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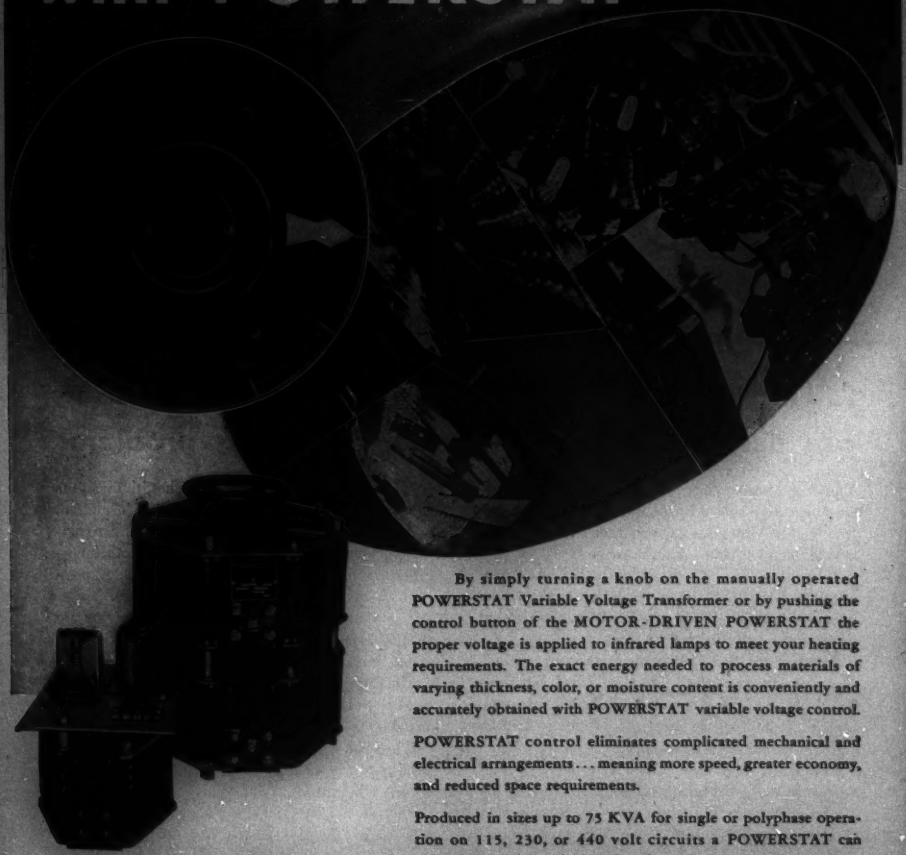

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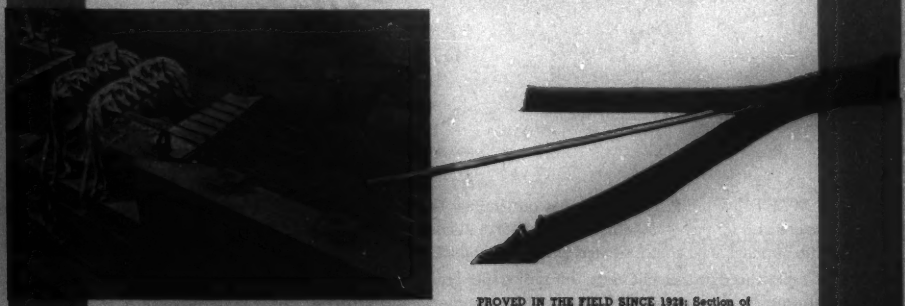

LASTING PROTECTION: After electrolytic cleaning, all Okonite copper wire passes through the Okoloy bath where, under carefully controlled temperature, the corrosion-resistant Okoloy coating is bonded to the conductor.

PROVED IN THE FIELD SINCE 1928: Section of Okoloy-coated wire removed for examination in 1941 after 13 years of service along right-of-way of a major railroad system, where it was continuously exposed to weather and to highly corrosive sulphur fumes. Note perfect condition of Okoloy coating and Okonite insulation.

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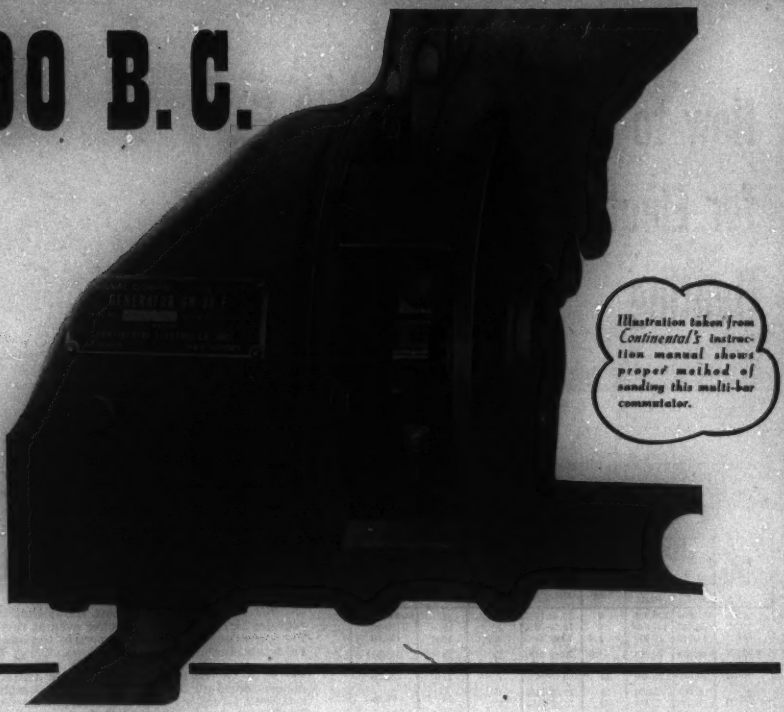

Illustration taken from Continental's instruction manual shows proper method of sanding this multi-bar commutator.

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How to Choose Tubes for Electronic Heating

Because so many factors affect the choice of tubes for electronic heating, RCA engineers have summarized here some of the most important ones, and have prepared the table below to enable you to choose tubes by power output rating and frequency.

RCA TUBE TYPE	POWER OUTPUT** at Max. Ratings		MAX. FREQUENCY		COOLING METHOD	AMPL. FACTOR	PRICE
	1 Tube Watts	2 Tubes Watts	@ Max. Input Mc	@ ½ Max. Input Mc			
9C21	100,000	200,000	5	25 @ 70%	W & F	38	$1,000.00
9C22	65,000	130,000	5	25 @ 70%	F	38	1,100.00†
892	14,000	28,000	1.6	20 @ 50%	W	50	190.00
892-R	10,000	20,000	1.6	20 @ 50%	F	50	380.00†
889	10,000	20,000	50	150 @ 50%	W	21	220.00
889-R	10,000	20,000	25	100 @ 50%	F	21	325.00†
833-A*	1,440	2,880	20	75 @ 65%	F	35	76.50
	1,000	2,000	30	75 @ 72%	W		
827-R	1,000	2,100	110		F	16	135.00
806*	450	900	30	100 @ 50%	N	12.5	22.00
8000*	375	750	30	100 @ 50%	N	16.5	13.50
8005*	170	340	60	100 @ 60%	N	20	7.00
826	86	172	250	300 @ 80%	N	31	19.00

*Indicates that intermittent ratings are available.
**Tube output values are shown. Deduct circuit losses for power to load.
N—Natural air cooling. F—Forced-air cooling. W—Water cooling.
†—Renewal price when similar radiator in good condition is returned prepaid at time new tube is purchased

Power Output: Not all RCA tubes available for electronic heating are listed above; those listed, however, make possible a range of tube output power in easy steps from 86 to 200,000 watts or more. Most types fall in the "medium mu" class, making them exceptionally stable, even under changing load, yet the "mu" is high enough to keep excitation requirements at an economical level. By utilizing tubes in push-pull or push-pull-parallel circuits, the power output required can be closely approached.

Power Supply: All power output values are for typical operating conditions under continuous service, and with d-c plate supply. If the oscillator tubes are to operate on a-c plate supply, the output power will be reduced.

In lower-power equipment, self-rectification may be economical; at high-power, however, the investment in power tubes is usually best used by supplying direct current to the plates, and getting full output.

Filament voltages supplied to tubes should be accurately adjusted and should not fluctuate. Attention to this factor will help to assure long tube life.

Output Frequency: The chart shows that the RCA tube line provides for relatively high power even at very high frequencies. For special applications not covered by the tubes listed here, write RCA tube engineers (address below).

Cooling: Of the tubes listed, all those delivering 1 kw or more require forced-air or water cooling. Where mobility of equipment is desired, forced-air cooling is usually preferred to water cooling. To prevent unnecessary maintenance, especially for water-cooled tubes, carefully observe the cooling requirements of the tubes.

Intermittent Service: Certain RCA tubes (marked *) have increased ratings for intermittent service.

Dependability: In industrial service, continuity of operation is very important. To assure dependability, electronic heating equipment should be designed with comfortable "safety factors," not only with respect to tubes, but also for other components whose failure might cause tube damage and outage of the equipment. Electron tubes are inherently maintenance-free devices designed to give long life under normal operating conditions.

Take plant conditions, such as heat, dust, vibration, humidity, etc., into account when installing electronic equipment just as in the case of other industrial apparatus. Ordinarily, however, special precautions should not be necessary.

Tube Replacement: RCA distributing and warehousing facilities simplify tube replacement problems, giving quick service in all parts of the country. Naturally, wartime conditions create an abnormal situation, but rated orders are handled with dispatch.

Engineering Aid: RCA tube application engineers are available for consultation on your electronic design problems. Your inquiries are invited. Write, stating your problem, to Radio Corporation of America, Commercial Engineering Section, 731 So. Fifth St., Harrison, N. J.

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Name.....

Company.....

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City..... State.....

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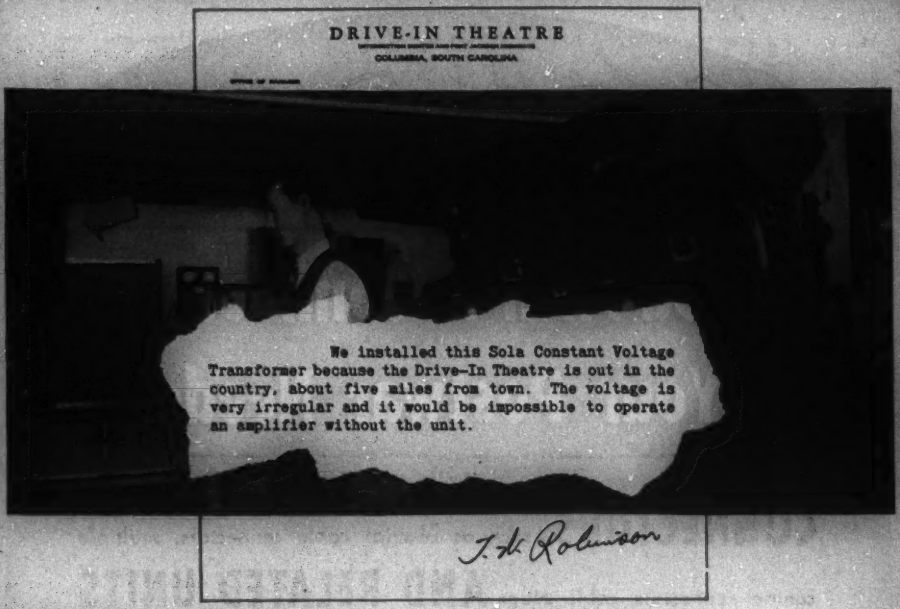
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COLUMBIA, SOUTH CAROLINA
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Even before Pearl Harbor the Drive-In Theatre of Columbia, South Carolina found it impossible to operate its amplifying system with the irregular voltages available from its power source. Only through the installation of a SOLA Constant Voltage Transformer were they able to correct this situation and deliver an acceptable performance to their public. Many other theatres have followed this example.

The lessons learned before Pearl Harbor, and greatly amplified by the increased tempo of industrial production, will contribute towards the future enjoyment of entertainment and communication facilities.

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AUGUST 1944

The Cover: A night view of the end of the Douglas *SBD* aircraft assembly line. More than 50 of the technical papers to be presented at the Los Angeles technical meeting, August 29–September 1, will deal with aircraft applications. Photo courtesy *Aeronautical Engineering Review*

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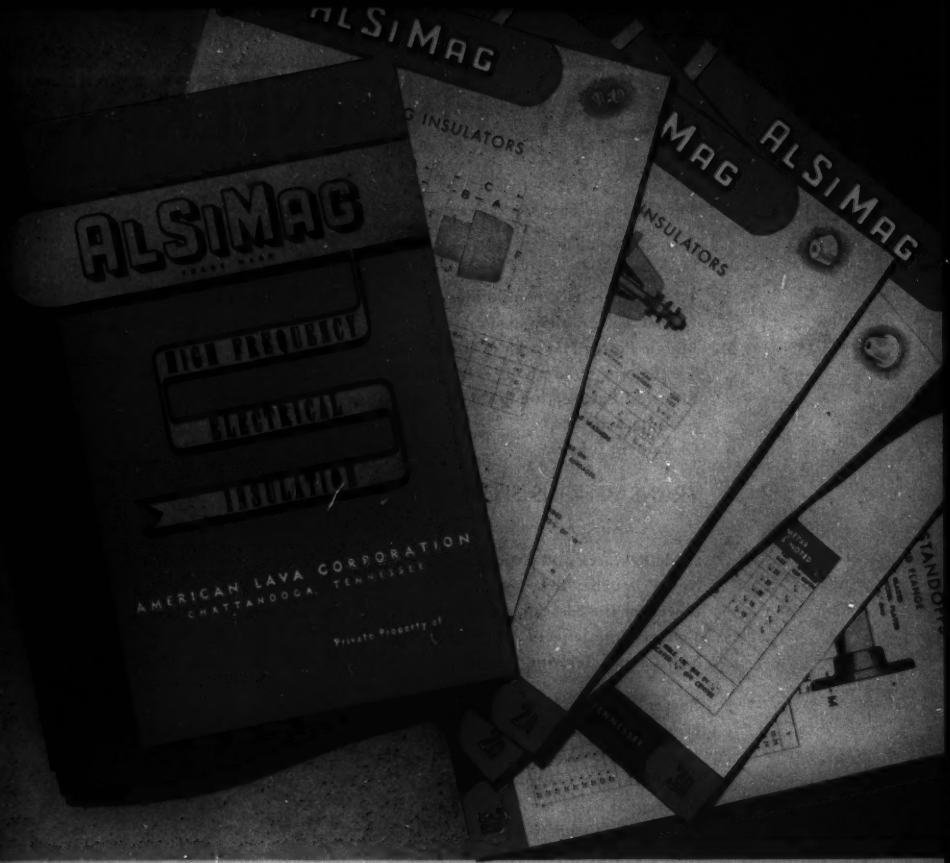

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Every engineer in the electronic field will appreciate the concise method in which the Electrical and Mechanical properties together with the design and dimensions of AlSiMag High Frequency Insulators have been arranged and tabulated for easy and quick reference in new Bulletin No. 143.

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ELECTRICAL ENGINEERING
VOLUME 63, NUMBER 8 AUGUST 1944

The Engineer's Present and Future Responsibilities

WILLIAM McCLELLAN
FELLOW AIEE

Integration of all the separate postwar planning now being done by government, business, labor, and management is urged in this article. The status of the engineer as a professional man entails special responsibilities.

EVERY professional man has hurdles to get over if he is to succeed. To start with, he must be a mechanic. The danger is that he will never be anything else. The medical man must be skilled in observations and diagnoses which can be purely mechanical. The surgeon must be an adept in dissection and tying knots. The lawyer must have a somewhat mechanical ability in stating definitely an idea, or meeting of minds, in words. Any honest so-called professional man strives to do the job at hand to the best of his ability. He wants to earn his pay. In this, however, he is no different from the honest toolmaker working to a thousandth of an inch. If their several abilities go no further, why should they be called professional men? What is the difference between the most highly trained mechanic and the professional man? I have no doubt many men would give many different answers. To me the answer is that the professional man never forgets human relations and the progress of human development. The true professional man sees more in his job at hand than a repair, a victory, or material achievement. Each such job at hand by which he earns his daily bread is part of a fundamental personal purpose to aid humanity in general. He means by his whole work and life to make the world better. He is willing also to give time and thought, for which he is not paid, in the hope of making human relations closer and more sympathetic. In short, he adds to his devotion to his client or customer a devotion to humanity.

The engineer in his race onward faces a special hurdle. I often illustrate this by a homely comparison. The young law graduate enters some law office as a cub. His first job may be to carry some papers to a client for signature. At the beginning his mind is set on a conflict between people, on a problem in human relations. The young engineering graduate gets a job at a drawing board or on construction. At this beginning he is studying materials and machines. These materials and machines are ultimately related to human needs, of course, but the engineer is not in contact with any particular humans involved. Therefore, there is a greater possibility that an engineer may confine his thinking and time to the materials and machines he may create or use. Unless he overcomes this particular hurdle, his professional status may suffer. Because engineers have not always been keenly aware of this hurdle and adopted special means to overcome it explains, perhaps, why they complain so frequently that the public does not give them as much professional status as the lawyer, doctor, and minister.

The never-to-be-forgotten fact is that each man and each woman is a citizen first. His or her responsibilities as a citizen always stand ahead of all others. Each chooses a vocation in order to earn a living, to be free, and to pursue his own happiness. But each of us has a talent, and the world as well as ourselves should benefit from the production of that talent. It is our present and future responsibility to make sure that the world gets its share.

Since Pearl Harbor, all our efforts have been centered on winning the war. Our production of old-type material as well as a tremendous volume of new types has far exceeded our original estimates. The engineer has had a tremendous share in this. Through his imagination and practical ability, new materials, new devices, new methods have astonished the world. It has been a magnificent achievement. Materially, the United States stands on a plane far above any other nation. There is just reason for pride. However, let us not forget the old saying, "Pride goeth before destruction and a haughty spirit before a fall." And also, in the language of the Book, "Let him that standeth take heed lest he fall."

Postwar days are coming and we can "fall." The United States then will face gigantic problems, and they will not solve themselves. We must plan the solutions, and yet we cannot afford to abate our efforts to win the war. What do we face? We face a world, much of which has been destroyed, and all of which will be imploring for help to rise out of poverty, hunger, and disease, and possible despair.

We shall face a United States with an enormous debt but with a productive capacity at least 60 per cent greater than we ever had in peacetime. We face a demand for a government of greatly expanded functions, the expense of which will overwhelm us unless government can operate efficiently without waste.

We face nations everywhere which will of necessity, because of economic destruction and dislocation, resort to state control and management of business. We have to wonder what the impact of this will be on us.

We face a demand from our own people that the individual be not submerged, that he be free to work out his business and social life as he wills within our enormously complex business and social structure. This is the "free enterprise" which we had in the early days of America. We want its return, as free individual enterprise.

In these circumstances it is indispensable that production be maintained at the highest possible level, that we use our huge productive capacity. Experts estimate that we should produce $140,000,000,000 worth. This is $40,000,000,000 more than we ever before produced in peacetime.

Such production, it is estimated, would help utilize 55,000,000 workers. This would mean no unemployment of employables.

Next—this huge production of goods and services must be placed in the hands of consumers. It must be sold. It must be sold at very low prices. All possible consumers must have enough money to buy what they can use.

Do not forget that this huge production, we have been talking about comes from

An address presented at the AIEE summer technical meeting, St. Louis, Mo., June 26-30, 1944.

William McClellan is chairman of the board, Union Electric Company of Missouri, St. Louis, Mo., and past president AIEE.

Past President McClellan addressing the AIEE summer technical meeting. At the right are President Nevin E. Funk and National Secretary H. H. Henline

all of us—managers, engineers, lawyers, doctors, sales workers, transporters, plant workers, farmers, miners, and others.

Low prices will come by top efficiency in every sector of production and distribution. Adequate purchasing power, a continuous supply of money to keep plants at top efficiency and to make sure that necessary new plants can be provided, will come if each producer gets his proper share in wages, salaries, interest, and dividends.

Yes, efficiency in every operation is the absolute necessity. Efficiency is by no means a new word to you as engineers. The best definition of engineering I have ever known is the efficient use of men and materials for the service of man.

Your job in peacetime will be far more difficult than what you did in war. In war there was one dominant motive. There was no question of expense. There was no uncertainty. There was no question of demand but only that of supply. No war producer could have any mistaken notion of getting along without you, or of not listening to you.

Our peacetime production will fail in its purpose, unless the same spirit prevails. That purpose is a very large one. It is not merely that everyone may have a job which will give him creature comforts and animal security. Men also have minds and souls. They need serenity and inspiration, as well as food and shelter. They need to live in the very broadest meaning of that word. They need to have everything there is to be had in life.

So, efficiency in production and distribution is only one of your responsibilities. Let us call it your vocational responsibility. I have no fear that you will not discharge this responsibility. You have proved it too often for there to be any doubt. But you have a responsibility far wider than any vocational responsibility. You have what I talked of as professional responsibility. In simpler terms you have a responsibility as a citizen.

The huge production and distribution of material goods and services must be accomplished within a governmental and social frame. There are those who think the frame must be a state-planned economy. It looks very much as if every other country in the world may be compelled to resort to a very great degree of governmental management of business, at least for some years. Opinion in the United States is against this. Nevertheless, we understand that, in our modern complex industrial world, governmental policing of business will have to be far more extensive than heretofore.

I tell you with all the force I have that, unless representatives of business, labor, farmers, professional men, and government sit down around a table and make this frame, all our vocational efforts will be blocked. Being blocked means utter confusion. History shows that when there is disunity and confusion the worst elements in society make progress.

All groups are planning, but there is no one national plan in the making for domestic life or for international relations.

What shape must this frame have which is to make possible merely our primary and basic postwar plans—$140,000,000,000 of production and distribution, and satisfactory jobs for 55,000,000 workers?

First, government must reorganize itself so as to perform efficiently and at least expense its enormously increased tasks of policing our economic activities and making possible social and economic security for all. This must be done so as to permit the greatest freedom for individual enterprise and to encourage the greatest effort of every individual in production.

Second, management and labor jointly must install a system of conference and action so that the greatest efficiency in production and distribution may be attained in order that goods and services may be had at the lowest possible prices. Neither can do this separately.

Third, a well-ordered scheme of taxation must be devised, so that all groups will pay their proper share and no group will be hampered in its efforts for the common good.

Fourth, wages, salaries, interest, dividends, must be allocated so that every man and woman shall be an adequate purchaser in order to have whatever his station entitles him to have for a satisfactory life, and so that he can do his share in providing risk capital for continuous economic progress. Too few people understand how important is the way a country is taxed to raise a large sum like $20,000,000,000. The method can spell success or failure.

Fifth, a system of money, credit, and tariffs must be arranged which will give permanent stability to our whole economic process, both domestic and international.

No matter what other planning we do, it will all arrive nowhere unless money, credit, and taxation plans are right and stable.

We could go into a hundred details that are being talked about quite vociferously just now. But, important as they are, they are details and not so important as the frame within which we must live and operate.

Getting this frame, so necessary to success, is not part of anybody's vocational responsibility. Vocational responsibility is a personal matter. It can be discharged within the walls of an individual office or plant. Getting the frame is a joint responsibility of all of us, thinking and working together.

The sad fact at present is that there is no such joint planning. Farmers, labor, business, professional men, and government are all planning—but separately. Suppose the Army, Navy, Merchant Marine, and the home front had all planned separately to win the war. Suppose there had been no general staff. In war the government, of necessity, makes the general plan and all of us fit our vocational plans into the general one.

We say we do not want peace planned that way. We say we want to resume democracy in peacetime. Do we mean it?

We think democracy is the best form of government but we had better understand that democracy is the most difficult form of government to operate.

We can have government of, by, and for the people, but only if the people plan together—not in separate groups.

Engineers, like lawyers and medical men, have very special responsibilities. They are educated men. They are trained men. They have special abilities. Please God, they will not stop at mere material effort. Please God, they realize that all their efforts and their training, all their intelligence, and all their devotion must be directed toward human welfare.

We pride ourselves on our material progress. We call it civilization. What matter if we talk across oceans, fly over mountains, travel at high speeds, see in New York some occurrence in London, if we are as ready to spring at each others throats as we were when we had none of these things. The Book says—"What shall a man profit if he gain the whole world and lose his own soul?"

Carrier Telegraph Systems

F. B. BRAMHALL
MEMBER AIEE

Since the invention of the telegraph a century ago, refinements have been made until as many as 144 automatic printers operate at 60 words per minute over a pair of wires. Some of the steps in this evolution are reviewed in this article.

IN THE TIME of Samuel F. B. Morse, inventor of the telegraph, a single telegraph transmission of perhaps five words per minute represented the maximum use that could be made of a telegraph wire. Today over 97 per cent of all telegraph communication in the United States is carried on by automatic printers, which are known as teleprinters or teletypewriters. The word-per-minute speed of such machines is 60, and as many as 144 of these machines are now worked over a two-wire pair. The relative wire economies of the modern system and that in use even relatively recently, when the telegraph sounder still clicked away its 20 words per minute, are obvious.

How these things are accomplished may be explained basically in simple language and diagrams. First, combinations of two things taken five at a time are sufficient to identify all the letters in the alphabet. Figure 1 shows the electrical circuits of a printer in which five letter-selecting magnets are operated by five conductors. Figure 2 shows the same result accomplished by operating the five selector magnets consecutively one after the other with only one wire but with the addition of a sending and receiving commutator. An analogy of this form of circuit, known as the multiplex, is shown in Figure 3 in the form of a belt conveyor carrying alphabet cards from three transmitting positions on the right to three receiving positions on the left. The sending dealer picks one card from each row, working from top to bottom, placing them on the belt. The receiving dealer distributes the cards as they arrive in a similar manner and in proper sequence. The rows correspond to printers, or channels, and on trunk circuits two, three, or four of these channels are operated on a single wire. This type of system has the disadvantage of wasting line time if, for example, one of the channels is idle. The varioplex or expanding-channel principal of operation overcomes this difficulty by skipping an idle channel and allowing the remaining working channels to operate at a more rapid rate. Using again the belt-conveyor analogy, Figure 4 shows a three-channel circuit with two channels operating and with the third in the act of entering. The small numbers under the belt represent the moment at which the channels can be entered and have no relation to the channel identity of the cards that happen to be above them. The sending dealer enters channel 3 by placing a card marked "IN" on the first space designated by "3" that the belt brings up. The arrival of such a card at the receiving station in such a position is the cue to include that channel in future distributions. This type system is used largely in customer-to-customer service where direct connections are necessary but the total business does not warrant a full-time channel. The line transmission problems met with either system are identical, and the carrier-current systems which will be described were designed primarily for four-channel multiplex working with the frequency of the signaling impulses at 66 cycles per second.

At this point a detail of terminology should be clarified. The word channel has, unfortunately, two distinct meanings, not alone in this article but in all telegraph-transmission literature. The printer-to-printer communication circuit on a multiplex system is called a channel. Then when a means was devised for sending the signals representing the intelligence of a four-channel multiplex over the wire with those of several other multiplexes such paths also were called "channels." Alexander Graham Bell was experimenting with telegraphy when he hit upon the idea of dividing the frequency spectrum into small pieces and telegraphing independently over each such piece, the currents being carried over a common transmission medium. The telephone incidentally was only a by-product of Bell's effort to provide multiple transmission paths for Morse's telegraph. Today the voice-frequency spectrum is divided with channel tuners, or filters. Ten voice-frequency channels separated by discrimination adequate to prevent inter-channel interference are obtained between 350 and 3,250 cycles. These are called voice-frequency channels only because the frequencies employed fall within the range used by the voice. The centers of the pass bands of these tuners are located at 300-cycle intervals from 450 cycles to

Essential substance of a paper presented at a meeting of the AIEE Philadelphia Section, April 10, 1944, commemorating the first commercial telegraph service.

F. B. Bramhall is transmission research engineer, Western Union Telegraph Company, New York, N. Y.

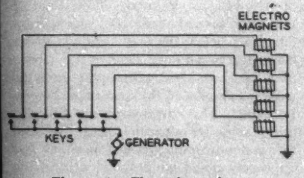


Figure 1. Five-wire printer

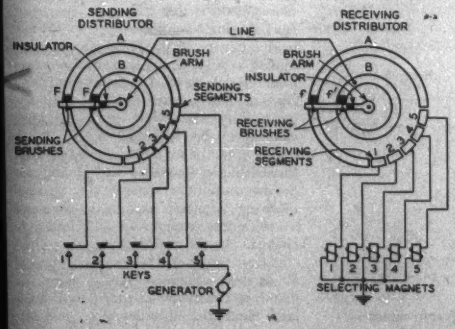


Figure 2 (left). One-wire printer

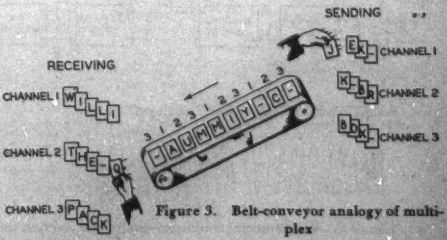


Figure 3. Belt-conveyor analogy of multiplex

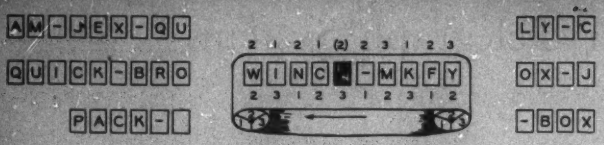


Figure 4. Belt-conveyor analogy of varioplex

3,150 cycles. The effective width of each band from input of sending tuner to output of receiving tuner is 160 cycles.

Until five years ago, signaling in these channels was accomplished by amplitude modulation, as illustrated in Figure 5. A source of carrier, a relay actuated by the multiplex signals, and a sending tuner comprise the essential sending-end equipment. The output sides of the sending tuners are multiplied together and the currents in the line are then seemingly a jumbled mess quite incapable of telling anyone anything. The situation is not actually so hopeless, however, since each receiving tuner (all of them multiplied together at their input ends) picks out its own frequency to the exclusion of all others. The device labeled demodulator is a rectifier which delivers a signal shown as *C* to the receiving relay. Transmission in the opposite direction must be done either on the same or another pair with an exact but inverted replica of this fundamental apparatus. So much for amplitude modulation, in some quarters now considered to be obsolete and disappearing from use. But before passing it should be noted that side bands of the nominal carrier frequency must be transmitted, first-order side bands spaced above and below the carrier an amount equal to the modulation (telegraph signaling) frequency. As a matter of fact, a little more band width than this requirement would seem to dictate is necessary in order to send, without distortion, pulses of varying length. A band width equal to two times the signal frequency plus 15 per cent gives substantially perfect results.

Frequency modulation, shown schematically by Figure 6, is the preferred method of operation today. The source of carrier frequency is an oscillator capable of having its frequency altered under the control of the telegraph signal sending relay. Practically for signaling at 70 cycles per second, the speed for which this system was designed, the oscillator frequency moves down 70 cycles to represent a marking impulse and moves up 70 cycles to represent a spacing impulse. It moves up and down gracefully, not abruptly, performing the transit in approximately the length of time measured by the duration of a signal pulse. Obviously the oscillator frequency then only passes through the nominal channel frequency, never halting there. However,

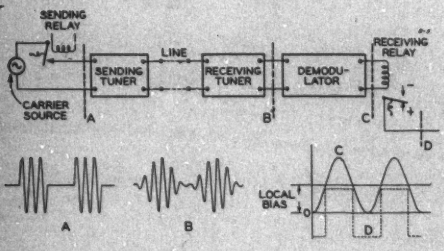


Figure 5 (left). Fundamental amplitude-modulated carrier telegraph circuit

A—Keyed carrier
B—Received carrier
C—Relay current
D—Relay operation

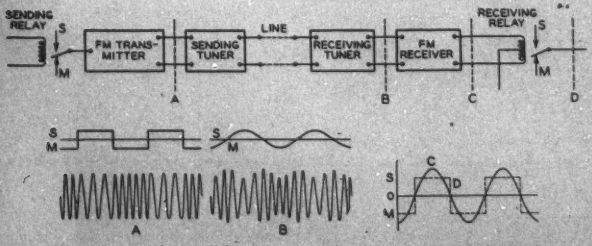


Figure 6. Fundamental frequency-modulated carrier telegraph circuit

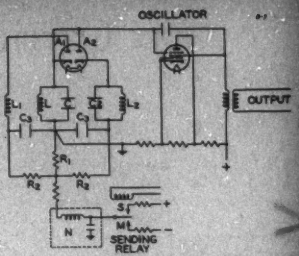


Figure 7. Schematic diagram of frequency-modulation transmitter

analysis of the resulting wave when continuous a-c signals are transmitted shows half the energy to be at the carrier frequency and just less than one quarter at either side frequency. This kind of frequency modulation is said to have a deviation ratio of one and is known to have side-band energy relations approximating very closely those of amplitude modulation. It is no more wasteful of spectrum space than amplitude modulation. The sending tuner on a frequency-modulation channel performs essentially the same function as on an amplitude-modulation channel, that of eliminating unwanted (higher order) side bands and other spurious frequencies which otherwise would let the channel interfere with the operation of its neighbors. The receiving tuner (and both tuners are the same tuners as used for amplitude modulation) picks out the frequencies intended for its detector as before. The detector in this instance is a push-pull arrangement of two linear frequency-discriminating networks so arranged that a frequency 70 cycles below nominal causes a direct current to flow in one rectifier tube and a frequency 70 cycles above the nominal value causes an equal current to flow in its mate. The currents of the two discriminators are separately amplified and fed, still push-pull fashion, to equal and oppositely poled windings of a receiving relay.

A comparison to the amplitude-modulation method is that of a polar system as against a single-current system. Frequency modulation provides the advantages pertaining to polar signaling, greater freedom from the effects of extraneous disturbing currents and greater freedom from the particularly distressing effect of level changes in the incoming signal. As a matter of fact, since the intelligence is now carried in the frequency change and not in the amplitude change, the channel receiving amplifier may be so designed as to ignore completely all amplitude change. In the words of the electronics engineer, the limiter stage has a range of 50 decibels. Figures 7 and 8 show the details of the frequency-modulation oscillator and the discriminator detector.

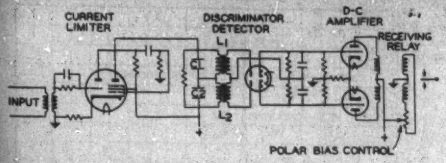


Figure 8 (left). Schematic diagram of frequency-modulation receiver

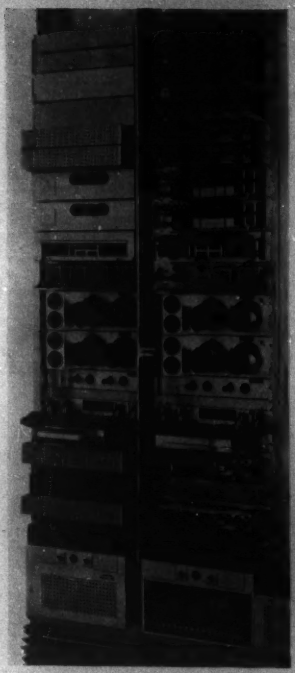


Figure 10. Standard channel terminals

Figure 9 shows the remarkable ability of the frequency-modulation channel to resist the disturbing effect of crosstalk noise. The same or greater imperviousness to impulse and fluctuation noise also can be shown.

Figure 10 shows four channels of frequency-modulation terminal sets including a great amount of monitoring and switching apparatus, a substantial part of which is a duplex grounded circuit repeater for extending the telegraph circuit to a point beyond the carrier terminal.

There is also a need for narrow carrier bands for single teleprinter operation. To meet this, a closer-spaced channel layout is employed. The channels are spaced 150 cycles apart and the effective band width is 80 cycles. Frequency modulation in these channels employs a deviation of 35 cycles above and below the mid-channel frequency. The operating characteristics of such channels are quite analogous to those of wide-band channels and the equipment is identical in appearance. For simplicity the discussion will be continued on the basis of the wide-band channels, noting here only that wherever traffic needs demand narrow-band channels they are substituted for the wide on the two-to-one exchange basis indicated by the 150- and 300-cycle spacing relationship.

Some voice-frequency four-wire circuits are operated in the eastern part of the United States. On these, ten channels of like frequencies are sent eastward on one pair and ten westward on another. Other four-wire circuits carry two groups of ten channels with frequencies up to 6,750 cycles eastward on one pair and westward on another. The low-capacity two-wire type *E* system carries a group of channels westward in its natural voice-frequency state and a similar group eastward with the bottom and top channels located at 4,050 and 6,750 cycles. Figure 11 shows the essential elements of *E*-system equipment. The transmission line at either end is terminated in the directional separation tuners. The westbound path, in addition to strategically located amplifiers, has tuners which pass only those frequencies headed west. The eastbound path is likewise walled in by tuners at either terminal which pass only the eastbound frequencies. A process of translating is used to pick up a block of voice-frequency channels from 450 to 3,150 cycles and drop them in the space from 4,050 to 6,750. At the west terminal, a particular channel, for example, the

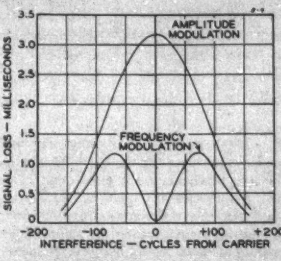


Figure 9. Effect of single-frequency crosstalk on amplitude- and frequency-modulated systems

$$\frac{\text{Crosstalk interference in 60-cycle modulation}}{\text{Peak carrier}} \Big/ \frac{}{\text{Peak interference}} = 12 \text{ decibels}$$

450 cycle, is appropriately mixed with some 7,200 cycles called the translating carrier. One result is the sum (7,200 + 450) 7,650 cycles, which falls outside the path beyond the upper wall of the directional tuner. Another result is the difference (7,200 − 450) 6,750 cycles which goes through the tuner and to the east channel terminal. It may be seen that in the new location the channel is still frequency modulated, that the swing is still 70 cycles above and 70 cycles below the nominal channel frequency exactly as it was, and that the side-band relations are the same. The same thing may be done with channels 2, 3, 4, and so on up to channel 10 at 3,150 cycles, the latter coming out at 4,050 and moving 70 cycles up and down in conformity to the multiplex signals. In many systems this translation is accomplished this way with a private mixer or modulator for each channel. In those to be installed henceforth one single modulator will translate them all in one operation accomplishing exactly the same result. At the receiving terminal the signals are mixed with 7,200 cycles and come out again between 450 and 3,150 cycles where the channelizing tuners separate them as already depicted. True, a by-product is some sum frequencies between 11,250 and 13,950 cycles, but these are ignored by the channel tuners.

Long type-*E* systems carry only eight or nine channels because of the proclivity of pass bands to become narrower and narrower as more and more tuners are placed in the path. Figure 12 shows that

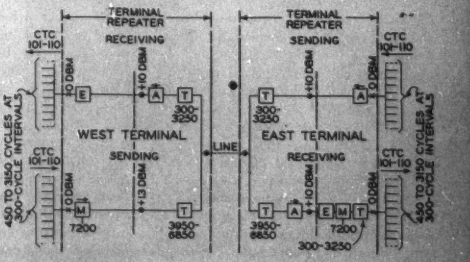


Figure 11. Block diagram of type-E system

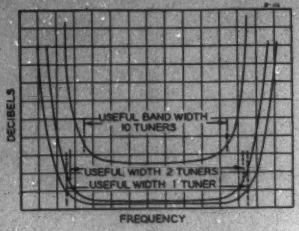


Figure 12. Effect of adding tuners in tandem

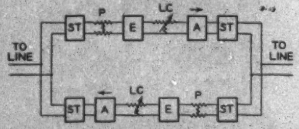


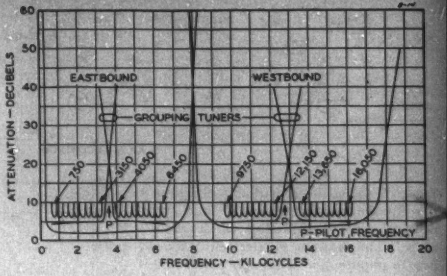
Figure 13. Block diagram of two-wire repeater

A—Amplifier
E—Equalizer
LC—Level control
P—Building-out pad
ST—Separation tuner

this unfortunate phenomenon is a matter of simple addition. The reason for more and more tuners in tandem in the transmission path is shown by Figure 13. Repeating amplifiers located at 200-mile intervals in long circuits must be employed to rebuild the signal strength. The eastbound amplifier must be constrained to amplify only those frequencies destined for the East hence it must be preceded by a separation tuner just like that used in the receiving side at the east terminal. It must also be followed by a tuner of like pass-range characteristics. The same reasoning applies to the westbound path. The result is two tuners in each path at each repeater station with attendant progressive narrowing of the pass band as the circuit length is increased.

The type-*F* system, in much more common use, provides two blocks of channels in either direction. The spectrum layout and the essential characteristics of the tuners required are shown by Figure 14. On *F* systems channel 1 is not used. Adequate separation between eastbound and westbound frequencies is allowed, however, so that circuits 2,000 miles in length may be worked without further loss of channels due to tuner constriction. Figure 15 shows the basic elements and method of translation employed in this system. Eastbound, the second block of channels is obtained by translation in every way analogous to that employed eastbound in the *E* system. Both westbound blocks must be relocated. This is done with but one translating frequency located midway between the two bands

Figure 14. Channel allocation of type-F system



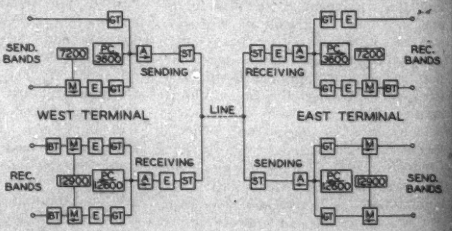
at 12,900 cycles. The difference frequencies are used for the lower band and the sum frequencies are discarded. The sum frequencies are used for the upper band and the differences are discarded. A pilot frequency located at 3,600 cycles eastbound and at 12,600 cycles westbound serves the dual purpose of controlling an automatic gain regulator at certain repeater stations and permitting the terminal attendants to communicate with each other on dispatching and like matters.

Another type of system called the *G* system accommodates four blocks of channels in either direction. Perhaps the present description of this system need go no farther than the statement that a novel and more efficient tandem arrangement of translators is employed. The problems of controlling unwanted products of modulation in equipment common to all channels were difficult in proportion to the system capacity but these have been successfully solved.

So far the principal concern seems to have been one of carrier-system design and little has been mentioned about transmission. The directions of transmission on the various systems are so chosen as to co-ordinate with each other and with systems used by the telephone company and the Western Electric equipment installed by the various railroad and pipe-line companies which have their own private communication systems. Figure 16 shows the directions of transmission employed with systems in common use by such corporations. Open-wire

Figure 15. Block diagram of type-F system

GT—Grouping tuner
ST—Separation tuner
BT—Band tuner
M—Modulator
A—Amplifier
E—Equalizer
PC—Pilot-channel terminal



transposition patterns used with the various systems are beyond the scope of this article. There is a tendency at present toward the matching of open-wire and cable junctions rather than loading the cables.

Under the impetus of present national-defense activity but subject also to the material restrictions imposed by war, carrier use in Western Union is expanding. Economies are thereby effected, but further than this, transmission efficiencies are so much improved as nearly to revolutionize certain former practices. Whereas on physical circuits from coast to coast several regenerative repeaters were required, on carrier circuits none are needed. Many multiplex circuits have been greatly increased in speed and when the country can be covered with a more complete network further gains in this direction can be realized.

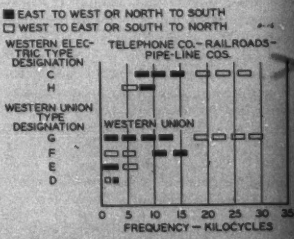


Figure 16. Frequency allocation of two-wire carrier systems

Mobile Power Plants for War-Torn Areas

Plants generating electric power are selected victims of war's destruction, and their replacement is vital to any rehabilitation program. Restoration is hastened by electric-generating facilities which may be moved on railroad tracks and placed in operation within a short time.

POWER PLANTS are one of the targets whose destruction is certain in any area over which battles are fought. Power, however, is the prime necessity in restoring devastated areas as soon as they cease to be battlegrounds. To make initial power available at the earliest possible moment, mobile electric-generating plants in the form of railroad trains which may be moved to selected sites and quickly placed in operation are under construction by several manufacturers in the United States. The first units have already been delivered.

A 3,000-KW POWER PLANT

One type of such a plant has been built by the General Electric Company and the American Car and Foundry Company. Providing 3,000 kw of electric power, it is embodied in a train of ten cars, consisting of locomotive-boiler cars, tenders, a turbine and condenser car, switchgear car, cooling-tower cars, and a car providing maintenance facilities and quarters for the crew. A view of the train is shown in Figure 1.

The fire-tube locomotive-type boilers operate at a pressure of 300 pounds per square inch and a temperature of 600 degrees Fahrenheit, and burn low grades of coal, fed automatically from the tender. The turbine car contains a 3,000-kw generator which delivers power at either 6,300 or 11,000 volts. The switchgear car contains the main switchgear, which is of the metal-clad type, together with indicating and control apparatus for the main generator. Two feeder circuits are brought out through each side of the car for connection to outside power lines.

Three cooling-tower cars contain wood cooling surface arranged in two cells. The wooden structure is mounted on a steel water basin on the car platform. Cooling air is supplied by four fans located in the top of the car and driven by direct-connected vertical motors, while water is circulated by a pump on each car. For operation where water is limited, the three cooling-tower cars are replaced by two radiator cars which require no water.

POWER PLANTS FOR 1,000 KW AND 5,000 KW

Portable generating plants to which the name "power train" has been applied are being built by the Westinghouse Electric and Manufacturing Company in two sizes—1,000 kw and 5,000 kw.

The 1,000-kw unit consists of one boiler car, one turbine-generator car, one cooling-tower car, and coal-handling equipment. A two-drum water-tube boiler is used, designed for steam at 420 pounds per square inch and 730 degrees Fahrenheit. The turbine-generator car contains the condenser and switchgear as well as the 1,000 kw three-phase 6,300-volt 50-cycle generator.

The 5,000-kw "power train," shown in Figure 2, is made up of eight cars, arranged as follows:

1 and 2. Main steam condenser.

3. Main turbine-generator unit and switchboard.

4. Air compressors and boiler-feed-water pump.

5. Boiler-feed-water supply of 10,000 gallons.

6 and 7. Main steam-generating equipment.

8. Work shop and quarters for the crew.

Coal- and ash-handling equipment also is supplied.

Air is used as the cooling medium in the main steam condensers, which are designed for operation at outdoor temperatures from −40 to 95 degrees Fahrenheit. Eight condensing sections are installed on each of the two cars, with four blowers on each car.

Power at 6,300 and 10,900 volts is supplied by the 50-cycle 3,000-rpm 0.8-power-factor 6,250-kva generator. The same car

Figure 1 (above). A ten-car mobile electric power plant for supplying 3,000 kw

A similar train is under test on an adjacent track in the background

Figure 2. Six cars under construction for an eight-car "power train" for supplying 5,000 kw

that carries the generator also contains a 75-kw Diesel-engine-driven 380/220-volt 50-cycle generator for use in starting and totally enclosed metal-clad switchgear, with circuit breakers of 150,000-kva interrupting capacity.

The two boiler-car units are essentially duplicates and are arranged so that the stoker ends are adjacent to each other. Each contains a two-drum bent-tube water-wall boiler designed to supply 40,000 pounds of steam per hour at a pressure of 660 pounds per square inch and a temperature of 750 degrees Fahrenheit, together with superheaters, economizers, induced- and forced-draft fans, and measuring instruments and control equipment. Compressed air is used to operate the boiler stokers, coal spreaders, and soot blowers, in order to reduce water loss.

One need for mobile electric power plants arose in Russia, where the rapid advance of the Russian Army required repair facilities close to the fighting lines for damaged tanks, trucks, and other war equipment. The Soviet Government has already accepted a number of the 3,000-kw trains for this purpose, but these will also be useful in restoring the operation of water supplies, hospitals, and sanitation systems.

Earlier in the war, mobile power plants of 10,000-kw capacity were built for the United States Navy for use as an emergency power supply, and these have been operated successfully in the United States.

The Fatigue Strength of Welded Joints

JONATHAN JONES

Metals may fail in service as a result of repeated cyclical variation of stress. A research project, sponsored by the Welding Research Council of Engineering Foundation, has been conducted to investigate the endurance limits of welded joints, and a summary of the progress and future plans of the working committee are given in this article.

THE FAILURE of a metal part in service by "fatigue" may be expected if:

1. The stress is not constant, but repeatedly varies in a "cycle" between a lower (minimum) and a greater (maximum) stress; the most severe cycle being that in which minimum and maximum are equal and opposite (full reversal).

2. The greater stress, maximum, is of a sufficient intensity.

3. The cycle is repeated a sufficient number of times, meaning hundreds or thousands or millions according to the severity of items 1 and 2. (For a more complete introduction to the subject see reference 1, which also contains an extended bibliography.)

If the range of stress in the cycle is not severe, or if the greater stress, maximum, is not great, the number of cycles to failure may be so many millions that for all practical purposes it may be considered indefinitely great.

For any given proportion of minimum to maximum, that is, for any particular type of cycle, the greatest value of maximum for which the number of cycles to failure may be considered indefinitely great is called the "fatigue limit" or "endurance limit."

For many structural parts it would be economically inadmissible to design so that maximum should remain below the endurance limit. In a railway bridge, for instance, in which virtually all parts are subjected to some sort of cyclical stress, maximum to minimum, it may be calculated that the total number of such cycles in say a hundred years of life, cannot exceed a few million. Judgment requires that the allowable unit stress be kept low enough to permit of those necessary millions, but not low enough for additional millions of cycles that will never occur.

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For nearly a hundred years, beginning with Woehler in Germany, experimenters have published data on the endurance limit of metals, and on the numbers of cycles to failure on various cycles and with various values of maximum. In general, the fatigue values for various steels have varied in proportion to the ultimate static tensile strength. These published values were based on specimens of uniform and, usually, polished form, and are unattainable in metal subject to the defects inherent in any form of fabrication for use.

Such defects must obviously exist in any structural joint. In a welded joint they may be due not only to weld defects such as porosity, inclusions and undercut, but without any of these they would exist in the change of exterior form at a weld, just as they exist at the shoulders on an axle.

Eight years ago a committee of the Welding Research Council was organized to obtain some usable data for the benefit of structural designers; the most definite objective was to supply the data needed by a committee of the American Welding Society which was writing a specification for welded bridgework.[2] The laboratory work, which still continues, has been carried out at the University of Illinois. Complete experimental data have been published from time to time by the laboratory, and condensed reports directed specifically at structural designers are issued by the committee.[3]

A summary of the results obtained to date will best be appreciated on the basis of a diagram explained in the committee's Report No. 2.

When a test is started on a given specimen on a given cycle (say zero-to-tension), a unit stress (maximum) is imposed which it is hoped will cause failure at a certain number of cycles. Of course the failure occurs at some quite different number. In the committee's program, usually six duplicate specimens are tested on the same cycle, three aimed at 100,000 repetitions

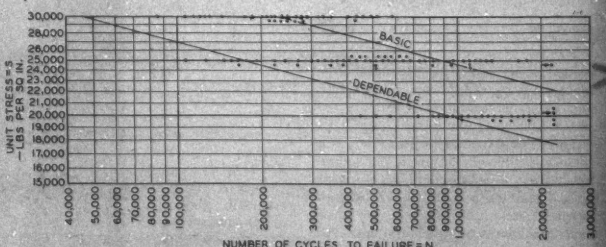

Figure 1. S/N relationship for butt welds in seven-eighth-inch steel plate

Cycle zero to tension

and three aimed at 2,000,000 cycles. Due to the unavoidable though usually nondetectable variations between supposedly identical specimens, the result is six values of maximum (called S), three low and three high, and with each a number (N) of actual cycles to failure, which numbers vary disappointingly from one another and from the 100,000 or 2,000,000 objective.

It has been found, over many tests of plain steels, that such associated S–N test values, if plotted on log–log paper will conform rather well to an inclined straight line for N between say 50,000 and say 4,000,000. It is convenient, and cannot create great error in application to design, to assume the same to hold true for welded specimens of a class. Acting on this assumption, the six (or more or fewer) S–N test results from a given series are plotted as points on log–log paper (with N for abscissa and S for ordinate), and a straight line is passed through the center of the left-hand (small N) and the center of the right-hand (large N) group. The intersection of this line with any S horizontal gives the number of cycles that should be resisted, on the average, with that S as maximum. The intersection of this line with any N vertical gives the maximum unit stress S which should, on the average, be endured N times and should then cause failure. Owing to the scatter in the data, this procedure must not be thought of as rigorous—only as useful for purposes of safe design.

Figure 1 is a condensation of a part of the data thus plotted and employed.

In Figure 1, each solid triangular symbol represents a test result on a "basic" X-rayed series of butt-welded specimens of seven-eighth-inch plate (ASTM A7, 60,000–72,000 tensile), tested without stress-relief and without removing or smoothing the weld convexity; the test cycle being from minimum equals 0 (full release of load) to maximum equals the tensile unit stress plotted. The upper sloping line is an approximate average through these points, and permits, as has been described, the scaling off of the "basic," or best obtainable N for a given S, or S for a given N, for butt welds of this character.

Each other plotted point in Figure 1 represents a test result from some one of numerous other series that were subsequently tested, using the same form of specimen, again without stress relief or improvement of as-welded form. These several series, however, were commercially obtained from various shops and field operations, and made by many qualified welders and in various positions. The scatter of these results is manifest. The lower sloping line in Figure 1 is not an average, but is what the committee after due deliberation voted to announce as "dependable." A designer is, in the opinion of the committee, justified in assuming that a butt weld in seven-eighth-inch A7 plate, made under American Welding Society specifications by a qualified welder but not stress-relieved or improved in external form, if subjected in service to a tensile force fully released and reapplied, may be depended upon not to fail at an S–N relationship below that represented by this line. If, for instance, he requires resistance to 1,000,000 repetitions, he finds that he can depend upon a maximum tension of 19,800 pounds per square inch, to which he will apply a "factor of safety" of his choosing.

While great accuracy for this method of interpreting the test data has already been disclaimed, it will be noted from Figure 1 that a considerable variation between the values of N obtained for a given setting of S, makes comparatively little difference in the position of the "average line," hence in the fatigue strength S that will be scaled off by the designer at his particular N.

Additional data are summarized in Figures 2 and 3. Figure 2 covers testing of butt welds on the cycle zero to tension, and Figure 3 on the cycle minimum equals maximum, or complete reversal. Only the averages are shown.

In Figure 2, cycle zero to tension, line 1 represents a few tests made on plain plate with mill scale planed off, and line 2 a larger number made on plain plate with the mill scale on. The contrast shows the effect of mill scale as a stress-raiser or stress concentration. These plain plates had the same critical area (five by seven-eighth inches) as the butt-welded plates.

Lines 3 represent butt-welded plates with the weld convexity planed off flush with the plate, specimens 3*a* being stress-relieved and specimens 3*b* being not stress-relieved. Line 4*a* represents butt-welded plates with the weld convexity undisturbed, stress-relieved. Line 4*b* represents the same but not stress-relieved, and is the same as the upper line in Figure 1.

In Figure 3, cycle complete reversal, the significance of the several lines is the same as for lines of the same number in Figure 2. Line 1 is missing, as no reversal tests were made on plates unwelded and planed.

All of these lines represent the averages of the respective tests; and all are on "basic" specimens, that is, specimens X-rayed to ensure highest degree of soundness in the welds.

The several variants represented by lines 1 to 4*a* were made only to show their relative effects on welds of one quality. These variants were not repeated on the several series of "commercial" butt welds recorded in Figure 1, as they have no commercial

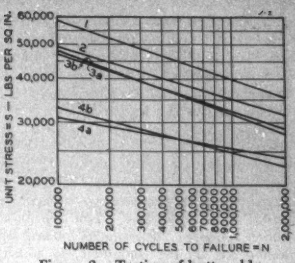

Figure 2. Testing of butt welds

Cycle zero to tension

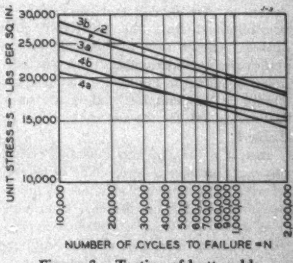

Figure 3. Testing of butt welds

Cycle minimum equals maximum, or complete reversal

place in bridge and building practice. Al "commercial" welds were tested with weld convexity undisturbed and in not-stress-relieved condition.

Further tests were made on butt-welded specimens of the same form, size and material as the preceding, in which the major stress, maximum, was compression instead of tension. On the cycle of complete release, or zero-to-compression, no failure was obtained at over 4,000,000 cycles with a compressive maximum practically equal to the specified maximum yield point of the material. Therefore in compression members in which minimum is also compressive, fatigue failure need not be considered a possibility.

On other cycles in which minimum was tensile and maximum was compressive, the fatigue strength fell off as minimum increased in intensity. This is shown in Table I.

It is not possible, for lack of machines, time, and money, to make such tests on every cycle of minimum to maximum that

Table I. Number of Cycles Endured Under a Fixed Compression and an Increasing Tension

Stress Cycle, Kilopounds Per Square Inch	Number of Tests	Number of Thousands of Cycles for Failure	
		Minimum	Average
−32.0 to 0	2	4164.4 (no failure)	4710.9 (no failure)
−32.0 to + 8.0	3	165.6	313.6
−32.0 to +16.0	3	23.7	36.0
−32.0 to +24.0	2	13.6	15.9

can occur in a structure. However, with reasonable values on the cycles (1) complete reversal, (2) zero to maximum, and (3) maximum-to-one-half maximum,* the committee has felt that the many intermediate cycles can be handled by interpolation. The method is illustrated in Figures 4 and 5.

Figure 4 is for butt welds in structural members in which the principal stress, maximum, is tensile; Figure 5 for those in which it is compressive. The respective curves represent "dependable" values, as announced by the committee, to which safety factors will be applied by the designer.

To construct Figure 4, the "dependable" values at $N=100,000$ and $N=2,000,000$ are obtained from the previously constructed curves such as Figure 1, for the test cycles just mentioned. These are indicated by circles in Figure 4. To construct Figure 5, "dependable" values are similarly obtained, for the test cycles listed in Table I.

Instead of 100,000 and 2,000,000 cycles, any other number of cycles could be chosen as critical for a certain structure or member, and another line drawn. It so happens that 100,000 and 2,000,000 are considered to be reasonable critical numbers for two different types of bridge member, those stressed by all parts of a long load and those stressed by a single heavy axle, respectively.

In Figures 4 and 5, abscissas are minimum, and ordinates are maximum, to the indicated scale. To the right of the vertical line, minimum and maximum are of the same sign; to the left, there is reversal. To use such a chart consider, in Figure 4, a member for which the stress sheet shows total stresses minimum (dead) $=-40.0$ kilopounds, maximum (dead plus live plus impact) $=+120$ kilopounds. The ratio minimum/maximum $=1/3$. Construct the line shown dotted, on a $-1:3$ slope. Its intersection with the upper line scales 22,200, and shows that the butt weld in this member should fail at 22,200 pounds per square inch if the maximum load cycle is repeated 100,000 times. The intersection with the lower line scales 14,800, and shows that the same weld should fail at only 14,800 pounds per square inch if the maximum load cycle is repeated 2,000,000 times. None of this information can in the nature of things be highly accurate, and it calls for the use of reasonable "factors of safety"; but it does afford the designer a possibility of reasonable balance over the various members of a structure. The committee on specifications for welded bridges of the American Welding Society is already building its design unit stresses around these data;

* When the cycle maximum to one-half maximum was tested in the "basic" series, with maximum tensile, the fatigue strength at 2,000,000 cycles was found to be above the static yield point. Therefore this cycle was not tested on the "commercial" series, and is not shown in Figure 4, as the static yield point replaces it as the controlling factor for design.

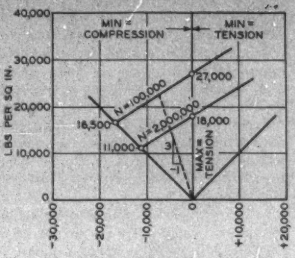

Figure 4. Dependable fatigue strength of butt welds in seven-eighth-inch medium steel plates

Principal stress tensile

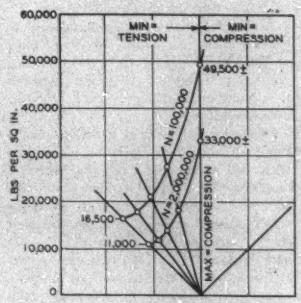

Figure 5. Dependable fatigue strength of butt welds in seven-eighth-inch medium steel plates

Principal stress compressive

and has developed, as explained in the appendix to its specification,[2] some design formulas which make the application simpler than, though mathematically identical with, the method of this paragraph.

The committee has in mind further tests of butt welds, including (a) welds in low-alloy steel and (b) welds in, instead of at right angles to, the direction of the stress.

The committee has made hundreds of other tests, involving the failure in fatigue of fillet, plug, or slot weld splices for plate members, and is commencing now to test flexural members such as rolled beams with welded cover plates, and three-plate welded girders, also various forms of welding used in reinforcing old bridges. It is operating, at the University of Illinois, four machines with a capacity of 200,000 pounds in tension or compression, and two with a capacity of 50,000 pounds.

The committee has not yet published any report of conclusions, other than on butt welds, but hopes in the near future to publish one on fillet, plug, and slot welds in bridge steel. This topic has required more time and care than were at first anticipated, because of the discovery of a relatively very low fatigue efficiency for material connected by fillet welds. Thus, when plates are spliced with double-lap fillet-welded splices, and tested on a cycle of zero-to-maximum, the main material may develop tensile cracks after 100,000 repetitions at 20,000 pounds per square inch or after 2,000,000 repetitions at only 9,000 pounds per square inch. This situation cannot be remedied by additional welding, since that does not reduce the stress concentration in the plate itself. Similarly, an I beam reinforced with top and bottom cover plates, fillet welded along the sides and across the ends, when tested on the cycle 1,000 to 33,000 pounds per square inch in the beam, failed after only 17,500 cycles by cracking across the beam flange just ahead of the welding.

Present test programs are aimed at developing as much efficiency as is commercially possible in fillet-welded material, and determining what that efficiency is. It is certain to prove far lower than for butt-welded connections.

In applying such data, it would be possible to commit gross extravagances by overestimating the extent of its applicability. On bridges, the specified loads are rarely present in the combinations and positions envisioned in the calculations for maximum stress in the heaviest members. When present, they are not necessarily of the maximum specified intensity. A small reduction in the maximum load makes a large increase in the number of cycles endured before failure. If the assumptions of the designer as to the maximum loads, and as to the number of times they will occupy the bridge in its lifetime, are held down closely to the true probabilities, extravagantly low unit stresses will not be called for by the test results. Undoubtedly, however, the specification for a bridge which contemplates the use of fillet-welded main connections, must go into these factors even at the cost of apparent complexity, or there can be either danger or waste.

The committee of the Welding Research Council is not setting up specifications for design. But it does hope, over the near future, to publish in the forms outlined in this article, all the factual data which the writing of such specifications requires.

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Electrical Engineering in the Postwar World

IV—Expanding Horizons

DAVID C. PRINCE
FELLOW AIEE

There is no saturation point in sight in the electrical industry, declares this electrical manufacturer; he indicates that we have hardly made a start in the use of electric power by mankind, but must find new and better ways of acquiring knowledge and putting it to work.

WE electrical engineers have too many developments in progress to subscribe to the sentiment that we live in a mature economy, even though we have been told we do. We feel confident that the future is going to flow on from the past. We have our natural laws through which we work. Most of us do not expect to break the laws of conservation of energy, at least not right away. We think that 100 per cent efficiency is a safe limit for the time being. But we can see that lots of these laws can be interpreted in another way. Laws are not necessarily limiting. Man-made laws are limiting, but nature's laws are partly for the purpose of directing us to the things that we can do instead of limiting us to the things that we cannot do. So, we take these laws, and we see what we might conceivably do in the way of using them as guides for the future.

We can arrange technical developments approximately in order of time. A great many technical developments that are in process right now have been stimulated much more than they would be ordinarily by the urgency of war, and we will be able to call upon them in the immediate postwar years. There are developments that we already know the beginnings of and others that we do not, in general, know too much about, but which will be made known as soon as the cloak of secrecy can be raised.

We have generators and transformers so high in efficiency that for the time being we need expect no large increase in their efficiency. However, that does not mean that we have come to the end of the road in those things. We still can make them smaller and can develop new materials to make them better in other ways than merely increases in efficiency. We are learning a good deal about how to make them. As we reach a point where a given piece of machinery can be standardized in some way, then it becomes possible to make a new set of advances which will reduce the cost of that machinery and thereby make it more available to mankind.

Some very conspicuous examples of that sort are coming to light as a result of the war effort. For instance, for the first time in history we have 30,000-horsepower steam turbines in quantity production. The result of that quantity production in the amount of productivity per man-hour can be measured. For instance, estimates were made on the initial number of man-hours which were required to make the turbines—we will call that 100 per cent. After production had gone on for five months, the required number of man-hours had dropped to 80 per cent. After production had gone on 20 months, it took 71 per cent as many man-hours to produce the turbine as it had taken before the thing was standardized and put on a quantity-production basis. We know that when we can say, for the time being, a thing is good enough, then we can put production techniques to work on it and reduce the cost by a radical extent.

It has been supposed that motors, according to calculations, might be saturating the field. Soon we might get all we want, and, since we know that many very old motors are still running well and giving satisfactory service, the motor business would be finished. That has not happened, however. If you look at the statistics, you will find that in 1929 about 79 per cent of manufacturing processes were electrified with motors—that could be electrified with motors. In 1939, ten years later, that fraction had reached 86 per cent.

The growth of electrification with motors cannot be measured by those ratios, however, because during that period the total amount of manufacture increased by a considerable degree. Also, the increase in the use of motors is not delineable by increase in electrification only, because we are discovering lots of things that can be done with motors that we did not know about previously.

Perhaps a conspicuous example of that is in the field of aeronautics. Originally, an airplane had one engine in it. The engine was driven by gasoline, and it had electric ignition. That was the only place where electric power was used, except for landing lights and a few similar applications.

Now, there are four-motored bombers which have over 185 motors in them, performing different kinds of functions. With the possibility of that sort of development, it is useless to talk about saturation, either in the number of motors or the uses to which they can be put.

We have other developments which lend themselves in the direction of more uses in the flexibility of our goods. For instance, in the past we have had hydraulic devices utilized for the control of such things as the big guns on the naval vessels to pro-

Essentials substance of an address presented at the Institute's 60th anniversary observance during the AIEE North Eastern District meeting, Boston, Mass., April 19–20, 1944.

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duce precise movements in elevation and azimuth. Now, we find by the application of well-known electrical principles, d-c power can rotate not only the turrets on vessels but also the turrets on a lot of airplanes where a higher precision and speed are used. This device is called an Amplidyne.

The Amplidyne can be used, too, for a good many other functions requiring graduated and modulated control of considerable power and yet responsive to a small force. We have motors as light as 25 pounds for a 35-horsepower motor and rotational speeds as high as 120,000 rpm. We have hardly begun to explore the uses of such motors.

Of course, uses of electricity are not being limited simply to motor devices. We also are using electricity more and more for a lot of other purposes. A large part of our alloy steel production is from electric furnaces.

We hear, also, about high frequency. That comes into the story of electronics, and electronics is able to do a great many things. We find, for instance, that, when it is desirable to introduce heat into the middle of a body, it can be done by high frequency, by eddy currents in the middle of the body, or by electrostatic effect. Or we can take the outside of a metal part and bring it quickly to a high temperature and chill it so as to cause a hardening of the surface. When we harden the surface and put it under compression, we find it is more or less immune to fatigue which starts in scratches on the ordinary surfaces. Whereas in the past it has been necessary to go over the parts of airplane engines with a great deal of care, now, if we have the surface under compression, it may be much less necessary. Perhaps, by small application of engineering and electricity we can replace a large amount of human effort now expended in polishing, and other processes.

The electrical genie also is probing into the region of activity in which man's brain has been depended upon largely in the past. We have cyclic processes in the oil refinery business where hundreds of valves have to be opened, one for a while, then closed, then another and another. We have electric brains by which those things can be all operated in sequence, so that the deadening monotony, as far as the human worker is concerned, is lessened; and a much more conscientious job can be performed—better than if we had to depend upon our memories.

In measurement, electricity can do things that have never been possible to do before at all. We measure the quantities of the volts—amperes. In addition, by virtue of the application of electronics, we can measure thickness and tension, and we can use photoelectric effect to perform operations formerly performed by the human eye. We can measure sound. In fact, the only ones of our five senses which have not yet been measured are taste and smell; and we have every reason to believe that, if there is a good reason why measurement of these is needed, a method can be found to do it.

The use of electricity in local traction seems, for the moment, to have passed its peak. Some further expansion in railroad electrification is in prospect. Technically, the way is open for further progress. If we accept existing systems as satisfactory, we can apply the quantity-production techniques to reduce costs greatly. If, on the other hand, new techniques are desired, we know how to develop those too. We could have single-phase-rectifier locomotives for 25 or 60 cycles or even high voltage (20,000 volts) direct current.

The Diesel-electric locomotive, of course, has a lot of electric power in it. We know there are something like 30,000 steam locomotives and only a few hundred Diesel-electric ones. These latter are developing rapidly, however, and so there are many opportunities for technical advances, and changes to be made here.

In shipping there are many places where electricity might be used and has not been used before. For a number of years we have had instances of electric propulsion. Ships and ferryboats and tugs can operate with this electric propulsion. During this war we have gone further still. A large percentage of the destroyer escorts and a good many tankers are electrically driven vessels. On the tankers electric power is employed not only to drive the ship but also to handle the cargo. This application may well be expanded to permit our cargo vessels to compete with those of lower labor standards.

Lighting is one of the most universal of our applications of electricity. In the lighting fields, we still can look forward to a considerable advance. At the end of World War I lighting experts were quite tickled to find places where they could apply an intensity of five foot-candles. Now they are talking in terms of 50, 75, and 100 foot-candles in a factory, and nobody questions it. So, as far as we know, there is no saturation point. I asked a lighting expert if we are likely to get any better lights, and he said: "Our present efficiency is 20 per cent. I don't know just how improvement is going to be made, but there is plenty of room for it." So there is an opportunity for someone to make radical advances in this field.

In the specific field, where electronics is used for communication, we know that there are many developments all ready to be offered to us. Frequency modulation was just coming into use before the war. We have had television for quite a while, and we know that the companies manufacturing such broadcasting equipment can make it "when," "as," and "if." So, it will probably not be very far in the future before there will be many television programs and receiving sets to receive them.

All of those things are very definitely in the cards. We can have many of them right after the war, if the public demand is such that we want to bring them out.

We have new materials and new ways of doing things, and it is hard to predict an end to these possibilities. For instance, a number of years ago the older engineers will remember that there was a long argument as to what the best frequency would be for electric-power transmission. They argued from 133 to 16⅔ cycles, and earlier systems employed various frequencies. Sixty cycles is standard now, but it is not necessarily a final thing. On some ships we use 93 cycles, I believe, and by increasing the number of cycles we can decrease the size of the apparatus. In fact, to make motors to drive airplane models, we have gone to 180 cycles, and even as high as 400 may be a standard airplane frequency. As a result, we have some motors which approach one pound per horsepower. That permits the use of these extraordinary electric motors in lots of places where we had supposed before they could not be used. And so, electric energy may be used in a great many new places.

One of the things served up to us periodically by the newspapers is the possibility of wireless transmission of power. At the present time wireless transmission of power has been rather inefficient. However, we now know a way to transmit power through the air, and we know we can transmit this power with considerable efficiency for a considerable distance with wave guides but without the use of wires. That does not necessarily mean that we will do it. The question is: Is that a thing that is going to pay its way in terms of human service?. We can also use high-voltage direct current, if we want to. When the systems were being developed, before our a-c transmission had reached anything like its present development, high-voltage d-c systems were used in some places abroad. Now, with our electronic techniques, we could revive them again—but, I say again, *if* we find we want to do it as a service to mankind.

There is another field still further into the future. It may never bear fruit, but it is a possibility. Some people have said: "Why can't we have a storage battery much better than we have now, one that can be charged up to provide light and power for summer camps?" That question has been propounded to the chemists and the scientists generally, and they have said: "No, you can't have that, because we have looked the whole table of chemical elements over, and we found none that give much more electric energy than you now have."

However, there are other possibilities. If we had a pound of radium, it would gradually disintegrate, throwing off rays of one kind or another. That would be a source of primary energy that would compare favorably with any other.

We know there are artificial radioactive substances. When the energy is radiated, the material changes from a material that is heavier back to a lighter one. So we know the possibilities of the change of matter into energy; and, although we do not know just how to get the matter to enter those changes, or how to control the changes, we do know how much energy there is. That energy is equivalent to 11,300,000,000 kilowatt-hours per pound of material. Of, if we have to use that power in the form of heat, it corresponds to 3.85 times 10^{13} Btu per pound.

We therefore have this potentiality. When people worry about the eventual exhaustion of all of our oil resources, just remember that here is a potential supply where one pound will give you 2,000,000,000 times as much heat as the best high-octane gasoline.

So, there we have a picture of what we may get in the way of technical developments. We know there are a good many more that have not been suggested here, although when we look back later we will see that the beginnings of knowledge about these other developments were here too. Every time an invention is made, some of you could say: "I should have known that. I should have done that."

In the realm of education, we are very fortunate that Maxwell conceived the idea of not limiting physics to making experiments and measuring and getting qualitative information from them, but making an actual mathematical analysis of what is going on. When it progressed from the purely scientific to the actual development of the practical art, we found people like Steinmetz and Lamme ready to carry on in the Maxwell tradition. They were to apply mathematics to electric-machine design and both reduce the labor and improve the accuracy of predicting machine performance.

When problems got too complicated for hand-power mathematics, the various forms of network analyzers were developed; and for those fields where the phenomena might not be linear, the Bush differential analyzer was developed. These forms of mechanized mathematics have enabled our electrical industry to advance far ahead of all others in replacing the purely empirical by an analytical approach.

These tools can now be applied to other forms of engineering. By these means many analyses will be possible which never were before. For instance, an airplane designer came to Schenectady and worked two weeks on a stress analysis. He made calculations on the time he had saved; he had done 17 man-years of work. Think of what that means, in applying the techniques that have been worked out, in the knowledge of how to do such things.

In making these advances, we have acquired some responsibility to communicate the techniques to the other engineering groups who have not had the same advantages up to this point. Of course, not only does that give us that responsibility, but it also brings home to us another thing. We have some responsibility for the acts of our brain children. I don't believe any engineers can justly be charged with being responsible for the war just because the things they made are being used for destruction; but at least there is a warning to us to make it our business to consider what we are going to do with the technical developments and to see whether we can direct them into the channels serving mankind instead of destroying mankind. In other words, we have an obligation to learn more about electrical engineering, and then we have an obligation to find ways to put that knowledge to work. And we have a further obligation to consider how that knowledge may be used and to see that it is used in a way to benefit mankind instead of bringing about destruction.

Now, how can we add that knowledge to the already overburdened industries. It seems to me that there is a considerable opportunity for a research of quite a different kind from a purely technical research. We know that in the Army training, in just a few weeks, knowledge has been imparted to men which has enabled them to do things which ordinarily they could not have done without taking a four-year college course. We know another thing as a result of this war—and we should have known it as a result of the last war—in peace times we have been in the habit of saying that everybody should have a four-year course; and then every little while, because of the pressure of unemployment, or something of that nature, we think that perhaps the course should be increased to six or eight years. Actually, these young men have been able, not after four, six, or eight years of college training, but after a few weeks' training, to take these mechanisms of a highly technical nature and get out of them the functions called for.

We have the obligation not only of getting the knowledge and using it in the way that I have described, but also of finding ways and means by which it may be imparted to young men in a shorter time, so that they can apply it for their own benefit and ours. We must find a way for those men who are capable of leadership to take the reins and go ahead. Our war experience has shown us there are many capable leaders. Look at the decorations on the shoulders of the men in the service; it is not necessary to become 50 years old before becoming a competent leader. That, also, is one of the possibilities to be considered by people having charge of the educational phases of our electrical engineering.

We know that there is no end to the learning; but we have to have new ways of learning it. In other words, there is no saturation in sight, but we must find new and better ways of getting the knowledge and putting it to use. The technical advances and the educational advances undoubtedly await us. We will have, in addition, the advances in the use of our knowledge in the things that electricity can do.

I assembled some figures on the extent to which our electric power is being used at present. I found that the most common single thing in the hands of the public is the electric iron. Of all the people who have electricity, 93.7 per cent have electric irons. Next on the list is radio receivers, 87.5 per cent. When we get down to electric ranges, we are already down below 13 per cent. And when we get down to some of the other things we are beginning to hear about, such as dishwashers, deep-freezing units, air conditioning, and so on, they do not appear in the percentage column at all; they are still less than one per cent, and we have no statistics on them. But, we can look forward to developments from many of these things; and even in the lines most highly saturated there is still quite a bit of room to advance because, although we have 93.7 per cent electric irons, still there are to be 1,500,000 new homes each year and each of those should have electric irons. We have a long way to go even in the houses already wired.

We read a good deal about the houses not wired. As a matter of fact, the urban homes are 94.8 per cent wired. Presumably, they all have electric lights, and most of them have the other electric devices. In the rural nonfarm homes 83 per cent are wired, but the other farm homes are down to 36.1 per cent, so that only one out of three of these places has electric power, and the percentage of full use of electric power on the farm is much lower still.

As to what the possible future use of electric power by industry is, we have no way of telling. When we increased the speed cutting tools through high-speed steel, we thought we had done the job, but with cemented tungsten-carbide tools such as Carboloy we increased it again. When we increased the amount of power in continuous-strip steel mill, we thought we were doing a job; but we find we can set that up again. It just seems possible to increase indefinitely the use of electric power both to the private consumer and to industry. We know that the United States leads the parade in the use of energy per person; we know that all of Europe has been far behind us. Then, you get into South America, Africa, and China, and a start has hardly been made. We can be sure we have not approached saturation. Indeed, we have hardly made a start in the approach of the use of electric power by mankind. There are paths leading into the future of technical development, paths to new methods of learning and teaching electrical techniques and training our leaders; paths into more widespread uses of electricity in the service of mankind.

INSTITUTE ACTIVITIES

The Future of the Institute—*A Message From the President*

I desire first to thank you for the great honor you have bestowed upon me in electing me your president. I am looking forward to my term of office as a further opportunity to serve the Institute and shall do what I can to maintain the high traditions associated with the office.

The Institute is celebrating its 60th anniversary and it may be a good time, therefore, to ask ourselves if it has carried out the purpose to which it was dedicated by its founders—"*the advancement of the theory and practice of electrical engineering and of the allied arts and sciences, and the maintenance of a high professional standing among its members.*" To find the answer, we have only to go into any library and look through a few of its Transactions or examine a few of its Standards, and there can be no question that the Institute has fully carried out its avowed purpose. It must be a tremendous satisfaction to all of us to look back at the solid record of achievement of those 60 years. Nevertheless, it is true that any organization must move with the times or die, and so it is probably also fair to ask ourselves if the purpose of the Institute has run its course?

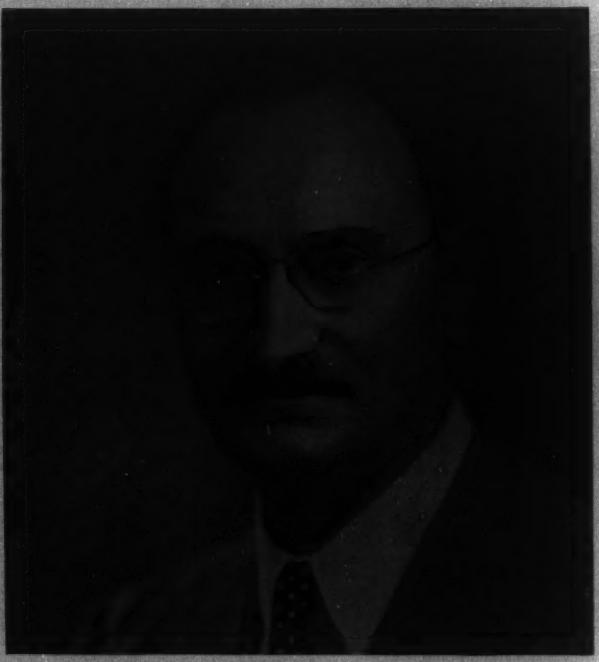
The answer to this is an emphatic "no." The electrical industry is still in its infancy, and it is sure that there will be a steady "advancement of the theory and practice of electrical engineering and of the allied arts" for many centuries to come. I visualize the Institute celebrating its 500th anniversary. Why not? We read of old-world universities celebrating even their 800th anniversaries, and their fundamental purpose has not changed in the interval, even though they may have changed the methods of carrying on their purpose. We must, therefore, see to it that the Institute be kept on the main highway which stretches still so far into the distance and not be diverted into branch roads where after a few years its main purpose and reason for existence will be lost in the swamps of other and unrelated issues.

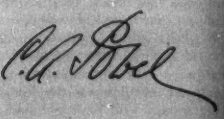
And what of the immediate future? The year ahead of us should be one of at least partial liberation—we should be able during the coming year to count on a cessation of hostilities in Europe if not in Asia. It is apparently the plan of the Government when this happens to release men gradually to normal employment. These men will be of various types. Some will be older men ready to go back to the work they dropped before they were inducted, some will be young men who did not have an opportunity of completing their technical training in a normal manner, and others will not have started their college careers at all.

Industry must find a way of absorbing the older men as they are discharged from the Armed Forces. This can probably be done with the elimination of women temporarily holding men's jobs and of men who have reached the age of retirement. Industry should in addition recognize its responsibility in helping these men bridge the gap in their technical experience caused by their term of service by providing suitable refresher courses.

Men not drawn from previous industrial occupations and having sufficient ability to justify college educations deserve and must be given an opportunity of acquiring such an education. The colleges will be confronted with problems arising from, first, transition from accelerated to normal course; second, the necessity of providing refresher courses for those men who have had as yet no opportunity of applying their college education outside of the services; and third, the complication brought about by the wide range of age of the freshmen classes. The Institute can assist the electrical educators, who make up such a large part of our membership, in the preparation of curricula for such students.

The schools should call on industry for any co-operative assistance they feel they need. Industry is vitally interested because its future is determined by the quality of the men graduated. The Federal Government will bear part of the expense of this transition program and it behooves us to make our plans so well that there can be no cause for the Government to make them for us.





Charles A. Powel, President AIEE 1944–45

Los Angeles Technical Meeting to Be Held August 29 September 1, 1944

Because of serious travel congestion, the Office of Defense Transportation has requested the cancellation of conventions. However, as the program originally planned for the Pacific Coast technical meeting is predominantly devoted to electrical applications to military aircraft, the meeting is to be held as the Los Angeles technical meeting. Members who do not have a direct interest in the papers to be presented should give serious consideration to travel conditions and whether or not their attendance would really aid the war effort.

The Los Angeles technical meeting will be held with headquarters in the Hotel Biltmore, August 29–September 1, 1944. In view of the extensiveness of the aircraft industry in the vicinity of Los Angeles, the program is principally devoted to electrical applications to military aircraft to aid the war effort. The papers will present various problems in connection with research, design, and development of electrical apparatus on aircraft which has to perform throughout the range of temperatures encountered in the tropics to the very low values at the high altitudes.

TECHNICAL SESSIONS

Fifteen of the 19 sessions arranged deal with aircraft electrical applications. Papers of broader interest have been scheduled in the morning sessions, whereas those which deal with more highly specialized subjects, such as automatic pilot control and instruments, motors, brush wear, radio, lighting, and high-potential ignition systems, have been scheduled in afternoon sessions. Several British papers will give valuable contemporary experiences. In addition to the aircraft sessions technical sessions on protective devices, power transmission and distribution, and industrial and marine applications will be held.

HOTEL RESERVATIONS

The Biltmore Hotel has been selected as meeting headquarters. Additional accommodations have been obtained at the Savoy, San Carlos, and Clark Hotels, all within two blocks radius.

All room reservations should be made through the hotels committee by means of the card which was enclosed with the announcement of the meeting and sent to the nearby territory, or by writing to R. F. Gheen, chairman, hotels committee, Ohio Brass Company, 417 South Hill Street, Room 1046, Los Angeles 13, Calif. Because of the great demand for hotel facilities reservations made by the committee will expire August 15.

Biltmore Hotel has no single rooms available; members should include name of person desired to share room, when making reservation. Clark Hotel accepts no single reservations. All rooms must be vacated prior to noon, September 2.

Return transportation should be arranged in advance.

ADVANCE REGISTRATION

Members who will attend the meeting should register in advance by filling out and mailing the advance registration card which accompanied the meeting notice. This will permit the registration committee to haue badges ready and prevent congestion at the registration desk. In accordance with regular practice a registration fee of two dollars will be charged all nonmembers excepting Enrolled Students and the immediate families of members.

LOS ANGELES TECHNICAL MEETING COMMITTEE

The members of the Los Angeles technical meeting committee are as follows:

T. M. Blakeslee, *general chairman;* P. L. Johnson, *assistant general chairman;* E. S. Condon, *secretary.* The chairmen of subcommittees are: P. L. Johnson, *technical program;* G. R. Woodman, *registration;* R. F. Gheen, *hotels;* Bradley Cozzens, *arrangements;* E. L. Bettannier, *reception and transportation;* Fred Foulon, *aircraft activities;* E. W. Morris, *electronics activities;* F. W. Maxstadt, *student activities;* A. D. Brown, *finance;* J. H. Vivian, *publicity;* P. L. Savage *inspection trips;* R. A. Hopkins, *educational*

Table I. Hotel Rates

Hotel	Single	Double	Triple	Suites
Biltmore		$7.00 to $10.00		$12.00 to $20.00
Savoy	$2.75 to $4.40	3.85 to 4.40		
San Carlos	3.00 to 4.00	3.00 to 4.00		
Clark		5.00	$6.00	

Tentative Technical Program

- **ABSTRACTS of most papers appear on pages 309–15 of this issue, pages 145–6 of the April 1944 issue, and page 227 of the June 1944 issue.**
- **PRICES and instructions for procuring advance copies of these papers accompany the abstracts. Only numbered papers are available in pamphlet form.**

Tuesday, August 29

9:00 a.m. Registration

10:15 a.m. Opening of Meeting

J. M. Gaylord, presiding

Address: **Brigadier General Donald F. Stace,** United States Army, commanding general, Army Air Forces Matériel Command, Western District

Address: **C. A. Powel,** president, AIEE

Report on District prizes

2:00 p.m. Electric Motors for Aircraft

44-197. Requirements for Aircraft Electric Motors. **E. R. Siefkin,** Lockheed Aircraft Corporation

44-210. Design Considerations of 400-Cycle Aircraft Motors. **M. B. Sawyer, Sr.,** Sawyer Electrical Manufacturing Company

44-201. Functional Design of Aircraft Electric Actuator Equipment. **C. E. Gagnier,** North American Aviation, Inc.

44-205. Problems in Applying Protectors to Electric Aircraft Motors. **L. W. Buell,** Spencer Thermostat Company

44-191. Inherent Overheating Protection of D-C Aircraft Motors. **C. G. Veinott,** Westinghouse Electric and Manufacturing Company

2:00 p.m. Aircraft Radio

44-180. Alternating Versus Direct Current for Aircraft Radio Power Supply. **D. E. Fritz, C. K. Hooper,** Westinghouse Electric and Manufacturing Company

44-211. Very High-Frequency Radio-Noise Elimination. **T. B. Owen,** Douglas Aircraft Company Inc.

44-209. A New High-Frequency Capacitor. **W. M. Allison, N. E. Beverly,** Sprague Electric Company

44-213. Radio-Noise Elimination in Military Aircraft. **G. Weinstein, H. H. Howell, G. P. Lowe, B. J. Winter,** Boeing Aircraft Company

2:00 p.m. Aircraft Ignition Systems

44-234. Analysis of High-Frequency Ignition Circuits. **A. W. Robinson, Jr.,** General Electric Company

44-189. Design of an Ignition System for an 18-Cylinder Aircraft Engine. **J. R. Harkness,** General Electric Company

Wednesday, August 30

9:30 a.m. Protective Devices

44-214. Field Determination of Current-Transformer Errors by the Secondary-Voltage Method. **E. C. Goodale, J. I. Holbeck,** Bonneville Power Administration

44-215. An Analysis to Determine the Optimum Busing Arrangements and Transmission Capabilities at Grand Coulee. **B. V. Hoard, G. W. Bills,** Bonneville Power Administration

44-192. 230-Kv High-Speed Reclosing Oil Circuit Breaker. **A. C. Schwager,** Pacific Electric Manufacturing Corporation

44-216. A New Distance-Type Relay With Adjustable Characteristics. **S. L. Goldsborough,** Westinghouse Electric and Manufacturing Company

9:30 a.m. Aircraft—General

44-217. Brief Survey of Power-Supply Developments on British Aircraft. **P. W. Carter,** British Air Commission

44-196. Airline Aircraft Electrical Equipment Maintenance. **W. A. Petrasek,** American Airlines, Inc.

44-218. Aircraft Electrical Horizons. **F. W. Godsey,** Westinghouse Electric and Manufacturing Company; **W. L. Berry,** Hughes Aircraft Company; **T. B. Holliday,** United States Army Air Forces

† Wiring Systems—Battery

12:15 p.m. Luncheon Meeting

Tentative Technical Program (Continued)

2:00 p.m. Aircraft Electricity

44-81. A-C and D-C Short-Circuit Tests on Aircraft Cable. **J. C. Cunningham, W. M. Davidson,** Westinghouse Electric and Manufacturing Company

44-200. Peak Voltages With D-C Arc Interruption for Aircraft. **Virgil E. Phillips, Walter P. Mitchel,** formerly with General Electric Company

44-186. D-C Arc Interruption for Aircraft. **J. S. Quill, L. T. Rader,** General Electric Company

CP.* Problems Involved in Extending the Use of Electric Power in Aircraft. **Mabel M. Rockwell,** Lockheed Aircraft Corporation

2:00 p.m. Aircraft Wiring

44-220. Solderless Terminals. **F. H. Wells,** Aircraft-Marine Products, Inc.; **J. C. Balsbaugh,** Massachusetts Institute of Technology

44-221. Historical Development of Electric Connectors. **E. J. Neifing,** Cannon Electric Development Company

44-222. Electric Connections on Aircraft. **L. A. Taylor, F. O. Stebbins,** General Electric Company

44-223. Cable Used for Transmitting Electric Energy in Airplanes. **M. F. Peters, J. J. Phillips, Max Kronstein, Helen B. Jealous,** Titeflex Incorporated

44-224. Requirements for Low-Voltage Aircraft Cable. **R. E. Hedges,** Douglas Aircraft Company, Inc.

2:00 p.m. Aircraft Motor Applications

44-207. One Type of Rotary Magnetic Clutch and Its Associated Brake Used on Aircraft Electric Motors. **Leo Andrews, Fred Shanely,** Lear Avia, Inc.

44-188. Considerations in Servomechanism Design. **S. W. Herwald,** Westinghouse Electric and Manufacturing Company

44-198. Some Aspects of the Application of Induction Motors to Aircraft. **H. J. Braun,** Westinghouse Electric and Manufacturing Company

44-195. Electric Gun Turrets for Aircraft. **J. D. Thompson,** General Electric Company

Thursday, August 31

9:30 a.m. Power Transmission and Distribution

44-185-ACO.** The Influence of Mutual Coupling of Transmission Circuits on Ground-Current Distribution. **M. J. Lantz,** Bonneville Power Administration

44-226. New 138-Kv Cable Lines in Los Angeles. **C. G. Mansfield,** Bureau of Power and Light, City of Los Angeles

9:30 a.m. Aircraft Electrical Design

44-228. Altitude Rating of Electric Apparatus. **Paul Lebenbaum, Jr.,** General Electric Company

44-229. Plastics in Aircraft Electricity. **E. B. Cooper, E. I. du Pont de Nemours and Company**

† Presentation and availability of these papers depends upon war conditions.

44-194. Aircraft Electrical Accessory Vibration Investigations. **D. R. Miller,** General Electric Company

44-227. Aircraft Engine Accessory Vibration. **J. Tyler,** Pratt and Whitney Aircraft

2:00 p.m. Aircraft Brush Wear

44-208. High-Altitude Brush Problem. **D. Ramadanoff, S. W. Glass,** National Carbon Company, Inc.

44-230. The Testing of Brushes for Life and Performance Under Various Altitude Conditions. **C. J. Herman,** General Electric Company

44-231. New Test Chambers for Aircraft Electric Apparatus With Particular Reference to Carbon Brushes. **E. R. Summers, J. F. Settle,** General Electric Company

2:00 p.m. Aircraft Lighting

44-206. The Development of Aircraft Position Lights. **Jack Vitol,** Civil Aeronautics Administration, Department of Commerce

†. Ultraviolet Lighting—British

44-233. Airplane Engine and Propeller Test-Cell Lighting. **D. H. Tuck,** Holophane Company

2:00 p.m. Aircraft Power Systems

44-204. Basic Considerations in the Selection of Generators and Batteries for Aircraft. **L. M. Cobb, H. M. Winters,** The Glenn L. Martin Company

44-199. Paralleling and Regulation of 24-28-Volt D-C Generators in Multiengine Aircraft. **Arthur Siegal, D. G. DeCourcey,** Boeing Aircraft Company

44-202. Circuit Protective Devices in Aircraft. **Walter Kenworth, E. V. Sundt,** Littelfuse, Inc.

Friday, September 1

9:30 a.m. Electronics

44-236. Vacuum-Tube Radio-Frequency Generator Characteristics and Application to Induction-Heating Problems. **T. P. Kinn,** Westinghouse Electric and Manufacturing Company

CP.* Electronic Frequency Changers (Summary of papers presented at summer technical meeting in St. Louis, June 26–30, 1944). **F. W. Brucker,** General Electric Company

CP.* Electronic Voltage Regulators for High-Voltage Circuits. **W. H. Pickering, A. W. Schardt, S. C. Snowden,** California Institute of Technology

CP.* Physical Aspects of Electroshock and Electronarcosis. **M. S. Plesset,** California Institute of Technology

CP.* Physiological Effect of Electric Shock. **C. F. Dalziel,** University of California

9:30 a.m. Industrial and Marine Applications

CP.* A Shipyard Public-Address System. **W. Ross Aiken,** The Permanente Metals Corporation

CP.* Electrical Propulsion of Ships. **W. J. Prise,** Moore Drydock Company

*CP: Conference presentation; no advance copies of papers available; not intended for publication in *Transactions*.

CP.* Arc-Furnace Regulators. **R. A. Geiselman, J. E. Reilly,** Westinghouse Electric and Manufacturing Company

9:30 a.m. High Voltages in Aircraft

44-203. A 120-Volt D-C Aircraft Electric System. **L. M. Cobb,** Glenn L. Martin Company

44-237. Impedance of 400-Cycle Three-Phase Power Circuits on Large Aircraft and Its Application to Fault-Current Calculations. **Major C. K. Chappuis, L. M. Olmsted,** United States Army Air Forces

44-238. Higher-Voltage D-C Aircraft Electric Systems. **W. L. Berry, J. P. Dallas,** Hughes Aircraft Company

†. A-C Systems—British

2:00 p.m. Aircraft Automatic Control and Instruments

44-187. Electrical Control in Automatic Pilots. **C. M. Young, K. E. Lynch, E. R. Boynton,** General Electric Company

44-239. Application of Electronics to Aircraft Flight Control. **W. H. Gille, R. J. Kutzler,** Minneapolis-Honeywell Regulator Company

44-179. Electric Automatic Pilots for Aircraft. **P. Halpert, O. E. Esval,** Sperry Gyroscope Company, Inc.

44-193. Influence of Electricity on Aircraft Instrumentation. **C. F. Savage,** General Electric Company

44-240. Instrumentation of 400-Cycle Aircraft Electric Systems. **A. J. Corson, A. G. Stimson, W. A. Soley,** General Electric Company

44-181. The Gyrosyn Compass. **O. E. Esval,** Sperry Gyroscope Company, Inc.

2:00 p.m. Aircraft Power Equipment

44-84. Blast-Tube Cooling for Aircraft Generators. **C. G. Veinott,** Westinghouse Electric and Manufacturing Company

44-241. Design Considerations for D-C Aircraft Generators. **J. D. Miner, Jr.,** Westinghouse Electric and Manufacturing Company

44-112. Aircraft Storage-Battery Design. **J. L. Rupp,** National Battery Company

44-184. Carbon-Pile Voltage Regulators for Aircraft. **W. G. Neild,** Bendix Aviation Corporation

44-190. A 40-Kva 400-Cycle Aircraft Alternator. **H. E. Kenepp, C. G. Veinott,** Westinghouse Electric and Manufacturing Company

2:00 p.m. Special Aircraft Equipment

44-182. Solenoid-Operated Hydraulic Valves for Aircraft Applications. **G. A. Goepfrich,** Bendix Aviation Corporation

44-242. Solenoid-Operated Control Valves. **V. W. Eckel, O. H. Wiegarver,** Precision Products Corporation

44-183. Electrically Heated Clothing. **G. H. Wotring,** General Electric Company

**ACO: Advance copies only available; not intended for publication in *Transactions*.

Co-ordination of Fundamental Electrical Graphical Symbols

Long-standing conflicts in electrical graphical symbols between the fields of electrical communications, power, control, and measurement have been settled under the pressure of war, which accelerated the overlapping of these fields and led to serious confusion in the industries affected.

The co-ordinated graphical symbols for capacitors, contacts, resistors, inductors, transformers, and operating coils are announced in American War Standard Z32.11-1944, "Co-ordination of Electrical Graphical Symbols," April 18, 1944, published by the American Standards Association, 29 West 39th Street, New York 18, N. Y., and priced at ten cents per copy.

Electrical Engineering will endeavor to conform to the approved symbols insofar as practicable. To expedite the application of the symbols, authors preparing manuscripts for submission to the Institute are urged to consult the Standards to assure conformity with approved practices.

Board of Directors Report to be Published in 1944 Transactions

In accordance with last year's policy made because of governmental limitations on the use of paper, the annual report of the AIEE board of directors will not be published in *Electrical Engineering*. The report will be pub-

lished in the 1944 volume of AIEE *Transactions*.

Members who so desire may obtain copies of the report from AIEE headquarters, 33 West 39th Street, New York 18, N. Y.

Aviation and Industrial Problems Top AIEE 1944 Summer Meeting Program

With 89 technical papers and some 30 conference papers presented and discussed in 21 technical sessions and 5 technical conferences, the Institute's 1944 summer technical meeting, held June 26–30, in St. Louis, Mo., set a new record in this respect. In spite of wartime transportation difficulties, attendance was almost up to the high level of the past four years, as indicated by the accompanying tabulations.

Sweltering heat, for which the Middle West long has been noted, greeted the early arrivals for the meeting and continued beyond midweek. Some of the meeting rooms in the Hotel Jefferson, meeting headquarters, were air-conditioned, but capacity crowds plus extreme heat somewhat overtaxed the cooling capacity so that the meeting was in reality a shirt-sleeve gathering. Comfortably air-conditioned sleeping rooms provided welcome relief after the hot days.

In subject matter, the emphasis of the technical papers was even more highly on war problems than at the previous technical meetings held since the United States was thrown into the conflict, even though previous meetings registered high levels of wartime flavor. Electrical applications to military aircraft topped the list with four sessions, and two sessions were devoted to industrial applications involving primarily wartime problems. As all approved technical papers, together with approved discussions thereon, eventually will appear in the 1944 AIEE *Transactions*, the sessions are not reported here. Available reports on technical conferences are presented in succeeding pages.

Recent Summer-Meeting Registration

Year	Location	District	Registration
1944	St. Louis, Mo.	7	1,142
1943	Cleveland, Ohio	2	1,179
1942	Chicago, Ill.	5	1,173
1941	Toronto, Ont.	10	1,204
1940	Swampscott, Mass.	1	1,010
1939	San Francisco, Calif.	8	945
1938	Washington, D. C.	2	827
1937	Milwaukee, Wis.	5	1,065
1936	Pasadena, Calif.	8	714
1935	Ithaca, N. Y.	1	901

On the program were the usual items of the annual business meeting and conferences of officers, delegates, and members, which included three parallel clinics on Section operation and management. Two medal presentations graced the annual-meeting program, the AIEE Lamme medal and the Faraday medal of the British Institution of Electrical Engineers; the latter marked the fourth award of that high honor to an American engineer. A general session at which three important anniversaries were celebrated and which included a feature address rounded out the program. Details of these and other features are given in succeeding pages.

A capacity crowd attended a luncheon meeting held Tuesday, June 27, jointly with the St. Louis Electrical Board of Trade. After the luncheon, Lieutenant Colonel T. B. Holliday (M '43) United States Army Air Forces, Wright Field, Ohio, and current chairman of the AIEE committee on air transportation, delivered an address "Aviation and the Electrical Engineer." The fact that modern airplanes can reach any part of the globe in 60 hours and therefore must operate in all climates presents a host of problems to aircraft designers, stated Colonel Holliday. He then proceeded to discuss some of the more important of these problems, with particular attention to problems associated with the electric systems. In no case, Colonel Holliday reported, has the electric system so far been shot out of any four-engine bomber that has "come home." J. W. McAfee, vice-president of the Electrical Board of Trade, presided.

Another special luncheon was staged on Wednesday, June 28, when the Circle Club of St. Louis, an organization of prominent engineers, entertained the officers, directors, and male headquarters representatives of the Institute.

As usual, many of the Institute's committees and subcommittees met during the meeting week, as well as the board of directors. In addition, the executive committee of the AIEE South West District met (the District in which St. Louis is situated), and a District student conference also was held.

The smooth functioning of all aspects of the 1944 summer meeting reflected the careful and painstaking advance planning that had been done by the meeting committee under the able chairmanship of B. D. Hull (F '39) South West Bell Telephone Company, St. Louis, who is a past AIEE vice-president and director. Other members of the committee and their specific assignments were as follows:

I. T. Monseth, *vice-chairman;* L. L. Crum, *secretary-treasurer;* F. A. Cooper, Jr., chairman, St. Louis Section; C. B. Fall, *finance;* C. H. Kraft, *meetings and papers;* B. T. McCormick, *registration and information;* R. G. Meyerand, *hotels;* E. S. Rehagen, *hospitality;* G. W. Thaxton, *transportation and trips;* L. F. Woolston, *publicity.*

Three Anniversaries Celebrated at St. Louis General Session

Brief historical addresses were delivered at the general session of the 1944 AIEE summer technical meeting, St. Louis, Mo., commemorating: (1) the 40th anniversary of the International Electrical Congress held in St. Louis in 1904; (2) the 60th anniversary of the AIEE; and (3) the 100th anniversary of the Morse telegraph. In addition, President Nevin E. Funk, who presided throughout the general session, also called attention to the fact that Charles F. Scott (HM '29) celebrates his 80th birthday this year. Doctor Scott served as the Institute's 15th president (1902–03) and has had a record of long and continuous service to AIEE; he was also vice-president of the 1904 Electrical Congress.

Following the celebration of these anniversaries, an address entitled "The Engineer's Present and Future Responsibilities," was delivered by Past President William McClellan, chairman of the board, Union Electric Company of Missouri, St. Louis, who also extended the official welcome at the opening session of the meeting. The essential substance of Doctor McClellan's address appears elsewhere in this issue.

40TH ANNIVERSARY OF INTERNATIONAL ELECTRICAL CONGRESS

Some of the significant events at the 1904 International Electrical Congress were outlined by A. S. Langsdorf (F '12), Washington University, St. Louis. This was the fifth in a series of World Congresses, the first of which was held in Paris in 1881 and the third at the Chicago World's Fair in 1893. Past

H. H. Humphrey (A '96, F '13) consulting electrical and mechanical engineer, St. Louis, beside the meeting bulletin board which displayed a photograph in which he appears taken during the 1904 International Electrical Congress

Analysis of Registration at 1944 Summer Technical Meeting, St. Louis, Mo.

Classification	Districts 1	2	3	4	5	6	7*	8	9	10	Foreign	Total
Members	75	151	82	33	173	8	276	7	10	11	2	828
Men guests	7	24	6	3	20	3	68					131
Women guests	6	13	5	8	20	1	35		3	2		93
Students	2	6	3	3	21	1	51	3				90
Totals	90	194	96	47	234	13	430	10	13	13	2	1,142

* District in which St. Louis is situated.

Future AIEE Meetings

Los Angeles Technical Meeting
Los Angeles, Calif., August 29–September 1, 1944

Winter Technical Meeting
New York, N. Y., January 22–26, 1945

North Eastern District Meeting
Buffalo, N. Y., Spring 1945

Summer Technical Meeting
Detroit, Mich., June 25–29, 1945

President Elihu Thomson headed the committee which organized the Congress and was elected its president at the opening meeting. Important papers were presented by electrical engineers and scientists of renown from several different countries.

One of the important developments of the 1904 Congress, Dean Langsdorf said, was the passing of resolutions that led in 1906 to the formation of the International Electrotechnical Commission; as a result, Congresses of the type held in 1904 have ceased to be held. At the close of that Congress, some of the delegates presented this resolution: "That America go forward, uplifting the banner of harmony and of liberty as it has done in the past, to the benefit not only of itself but of the nations of the whole world."

AIEE 60TH ANNIVERSARY

"The Institute may have turned the corner from its lusty youth, but certainly there are no signs of waning vigor," declared Vice-President W. E. Wickenden in his remarks on the Institute's 60th anniversary. "The founding, 60 years ago, was an act of faith which has been richly and amply justified by works," he continued. "It was the prospect of the International Electrical Exhibition which was to be held in Philadelphia in the fall of 1884 under the sponsorship of the Franklin Institute . . . which gave occasion for the founding of AIEE."

Pointing out that the process of industrializing the United States in a big way began in about 1880, Doctor Wickenden said that engineers then were becoming conscious of one another and engineering was becoming conscious of an enlarging common destiny. These circumstances led to the founding of nine engineering organizations between 1880 and 1885 and of that group the AIEE is clearly most outstanding. From the prospectus issued before the first meeting, Doctor Wickenden read: "It is proposed to follow the model of existing engineering societies whose members assemble, read, and discuss papers and matters relating to their trades or professions, and at the same time enjoy personal and social intercourse, all of which is conducive to improvement and advancement in ideas, theories, practice, business and good fellowship," and the plan of organization included not only meetings, papers, and discussions, but also "a museum, a library, original research, protection from unfavorable legislation, and the settlement of disputed electrical questions."

"Rarely has any organization needed so little reorienting in its aim and its method as has the Institute during this 60 years," Doctor Wickenden continued. "Borrowing solidity of aim and organization from the senior societies of engineers, striking a prophetic note from the beginning, emphasizing fellowship, equally with research and invention as a fertilizing force, the AIEE was launched on a career which has been striking in its consistency, vigor, and fruitfulness. It has been and still is a young man's organization. It is an organization whose growth has overtopped that of its sister bodies.

"Today, it is probably the largest organization among the technological professions of the world, and it has given a leadership worthy of this youth and vigor. It has led and still leads in the fostering of international fellowship. It has led and still leads in standardization and was the first official group representing scientists, designers, manufacturers, and operators to codify experience and achieve mutual understanding for the advancement of the art.

"It has led and still leads in the decentralization of its activities. It led notably in the enlistment of students and in the fostering of education. It led through its unforgettable president, Charles F. Scott, in inducing Andrew Carnegie to provide a common home in New York for the engineering profession, thus setting in motion forces making for the solidarity of our profession which have yet to reach their full fruit.

"It has created a monumental literature. It has given stimulus to research of incalculable fruitfulness. It has engendered in the electrical industry a spirit of co-operation and emulation. You know that it is an extraordinary industry, a competitive industry, but one marked by striking spirit of mutual interest and of emulation. Each profits as all profit under the aegis of the Institute.

"From the beginning there has been no cleavage between the engineer as scientist, the engineer as inventer, the engineer as designer and builder, the engineer as operator, the engineer as administrator, and the engineer as public leader and benefactor. All have been comprehended within the Institute's large conception of the engineer and of his purpose in our society. To each of us the Institute has given a greatly enlarged opportunity for service and for recognition, and an added sense of personal and professional dignity, a heightened consciousness of obligations to our colleges and to society, an awareness of a mission which transcends the details of our daily jobs.

"It is therefore fitting that we should pause for a moment of homage to the founding fathers, men of faith, wrestlers with nature, searchers after scientific truths, organizers of experience, creators of industries, inspirers of youth, servants of mankind, and founders of a great tradition—a heritage we are proud to share and to which we dedicate ourselves anew."

TELEGRAPH CENTENNIAL

The telegraph industry gave the initial impetus to all of the multiplicity of electrical industries as well as many affiliated industries declared F. E. d'Humy (F '30) Western Union Telegraph Company, New York, N Y., in commenting on the 100th anniversary of the telegraph. We owe it to the persistence of Samuel F. B. Morse, artist turned inventer, that the electromagnetic telegraph was successfully demonstrated on May 24, 1844. "Mr. Morse was not only responsible for that great movement but through the efforts that were being made to push the telegraph industry into a real commercial activity, he was instrumental in bringing this society into being," Mr. d'Humy continued. "It was the getting together of 21 telegraph men, and four others, that really initiated the foundation of this great society of the AIEE," and its first two presidents were telegraph men. He also pointed out that Andrew Carnegie who donated the Engineering Societies Building in New York to the national engineering societies was a telegrapher in his younger days.

Referring to the 100th anniversary celebration of the transmission of the first telegraph message that was held in Washington, D. C., May 24, 1944, Mr. d'Humy explained that this was commemorated by reenactment of the actual transmission of that famed message, "What Hath God Wrought?" The message was transmitted from the same room in the Capitol to the same old railroad station of the Baltimore and Ohio Railroad in Baltimore, Md., and over the original instruments that Morse used 100 years ago. As so much had been written in newspapers and magazines throughout the United States on this celebration presenting many and varied views of this great happening, Mr. d'Humy said that there was really very little that he could add. He closed his remarks by inviting those present to attend a special technical session to be held in the afternoon of the same day at which three papers were presented reviewing progress in telegraphy during the hundred years following Morse's famed demonstration. These papers will be published in the 1944 AIEE *Transactions*.

Two Medals Presented at 1944 AIEE Annual Meeting

Constituting the opening gathering of the 1944 summer technical meeting in St. Louis, Mo., the annual AIEE business meeting convened at 10 a.m. Monday, June 26. On the agenda were the usual annual items of Institute business, including the report of the board to the membership, the treasurer's report, tellers' report on election of officers for 1944–45, and report on award of prizes for 1943 papers. The program also included presentations of the AIEE Lamme medal and the Faraday medal of the British Institution of Electrical Engineers. The meeting was concluded with an address by President Nevin E. Funk, who presided.

Before the business of the morning got under way, Past President William McClellan, Union Electric Company of Missouri, St. Louis, extended the city's official welcome to those attending the summer meeting. Declaring that an annual Institute meeting had not been held in St. Louis since 1904, he called attention to

the tremendous changes that have taken place since that time. "I see a greater need than ever," he said, "for the AIEE annual meetings, these great get-together meetings, because the progress of events have so enlarged our fields of activity."

Speaking of the early days of the Institute, Doctor McClellan said that while the organizers were spurned as upstarts and given little credit, they did do one or two things that have been acknowledged. "We introduced accuracy; we introduced meters, and the whole field of engineering is using meters today; they never thought much of metering until we came along. And then, our field is becoming more and more fundamental so that today electrical engineering and chemical engineering are two great divisions of engineering, frankly, upon which all others must depend more or less."

REPORT BY SECRETARY

"During the past year the Institute has continued co-operating in the war effort at every opportunity," said National Secretary H. H Henline in presenting an abstract of the annual report of the board of directors. He reported that the Sections had set a new record in the number of meetings held during the fiscal year, totalling 743; of these 150 were technical-group, Subsection, or other types of special meetings. During the year, the last remaining part of the United States outside of Section territory was assigned to Sections, so that every member in the United States now is a member of some Section. He also called attention to the excellent work of the Student Branches which have been seriously handicapped, because so many of the students have gone into active military service.

A further increase in the total Institute membership was reported, the total at the end of the fiscal year being 21,407; since then the membership has increased still further and soon will be at the 22,000 mark.

Because of the current critical shortage of paper, the board report will not be published in *Electrical Engineering* this year. Pamphlet copies are available at Institute headquarters to AIEE members on request.

REPORT OF THE TREASURER

In the absence of National Treasurer W. I. Slichter, National Secretary Henline also presented the treasurer's report for the year The report showed that the Institute's income was the greatest on record and also that for the first time in years the market value of its investment is greater than the book value. A comparison of the current year with the preceding year is shown in an accompanying tabulation. As indicated in the table, the book value of all reserves was $315,225.29. Adding accrued interest, cash in reserve, and cash in general funds gives a total of $401,100 41, compared with $382,455.50 for the preceding year.

The Institute's Financial Situation in 1943–44 as Compared with 1942–43

Item	1943–44	1942–43
Receipts for the year	$434,660.36	$391,948.41
Out-of-pocket expenditures	331,344.39	354,377.70
Allocated to pension fund	85,000.00	
Total expenditures	416,344.00	
Gain	18,315.97	37,570.71
Book value of all reserves	315,225.29	278,398.33
Market value of all reserves	323,441.37	275,190.03
Book value of all reserves	315,225.29	278,398.33
Accrued interest	116.42	462.62
Cash in reserves	32,009.57	49,390.36
Cash in general funds	53,749.13	54,204.19
Total assets	401,100.41	382,455.50

At the speakers' table during the annual meeting. Left to right: Irving Langmuir, General Electric Company, Schenectady, N. Y., Faraday medalist; A. P. M. Fleming (F '34) Metropolitan-Vickers Electrical Company, Ltd., Manchester, England, and local honorary secretary of AIEE for Great Britain, who presented the Faraday medal to Doctor Langmuir; A. H. Kehoe (F '25) Consolidated Edison Company of New York, N. Y., Lamme medalist; President Nevin E. Funk; President-Elect Charles A. Powel; National Secretary H. H. Henline

REPORT ON ELECTION

The report of the committee of tellers was read by National Secretary Henline, and the nominees officially designated by the national nominating committee were declared elected to the various offices for their respective terms beginning August 1, 1944. The new officers were announced in the July issue (*page 268*).

Following the reading of this report, President Funk introduced President-Elect Charles A. Powel and performed the customary ceremony of pinning the president's badge to his lapel. Mr. Powel then spoke briefly, expressing his appreciation for the great honor the Institute had bestowed upon him. Commenting on the Institute's 60th anniversary, which was celebrated at the St. Louis meeting, Mr. Powel called attention to the solid record of achievement of those 60 years and envisioned the AIEE celebrating its 500th anniversary declaring that "there will be a steady advancement of the theory and practice of electrical engineering and of the allied arts for many centuries to come."

REPORT ON PRIZES FOR PAPERS

Prize winners for papers presented during the calendar year 1943 were announced by F. A. Cowan, chairman of the committee on award of national prizes. The prize-winning papers, together with certain District prize papers, were listed in the July issue (*page 268*). Among the various prize winners, only two were present to receive their awards: L. R. Ludwig (M '41) Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., coauthor of a paper with W. M. Leeds (M '38) of the same company; and B. R. Teare, Jr. (F '42), Carnegie Institute of Technology, Pittsburgh, coauthor of a paper with Mrs. Josephine R. Webb (A '41) formerly at that Institution, but now with the Westinghouse Company. A letter was read from the winner of the national Branch paper prize, R. W. Cronshey, formerly at the Michigan College of Mining and Technology, Houghton, who is now in military service overseas.

LAMME AND FARADAY MEDALS PRESENTED

In addition to the usual presentation of the AIEE Lamme medal, this year's meeting was honored with the presentation ceremonies for the Faraday medal of the Institution of Electrical Engineers, Great Britain. The former went to A. H. Kehoe (F '25), vice-president, Consolidated Edison Company of New York, N. Y., for "pioneer work in the development of a-c networks and associated apparatus for power distribution"; the latter to Irving Langmuir, associate director of research, General Electric Company, Schenectady, N. Y., for "his outstanding contributions to electrical science."

In describing the Lamme medal and the conditions under which it is awarded, S. B. Williams, chairman of the Lamme medal committee, pointed out that the medal is awarded annually by the AIEE for "meritorious achievement in the development of electrical apparatus or machinery." H. R. Searing (F '30) of the Consolidated Edison Company of New York, outlined the medalist's achievements, and in his response Doctor Kehoe narrated some of the events that took place during the development of successful multiple-feed a-c network distribution. The essential substance of the presentation addresses is scheduled for publication in a subsequent issue.

A. P. M. Fleming (F '34) of the Metropolitan-Vickers Electrical Company, Ltd., Manchester, England, presented the Faraday medal to Doctor Langmuir, on behalf of the Institution of Electrical Engineers, first briefly describing the conditions of award and mentioning some of the medalists' many contributions. He explained that the medal is awarded not more frequently than once a year for "conspicuous engineering or industrial achievement in electrical engineering, or for a notable service in connection with the development and advancement of electrical science in engineering." It is awarded without reference to nationality, place of residence, country of residence, or membership in the Institution. Three American

engineers have previously received the medal: Elihu Thomson in 1927; Frank B. Jewett in 1935; and W. D. Coolidge in 1939. The mutual dependence of England and America in the fields of science was emphasized by Doctor Langmuir in his response. He pleaded for a greater recognition of scientific endeavor by government and urged that incentives be provided to stimulate science and invention after the war. Essential substance of these presentation addresses also is scheduled for inclusion in a subsequent issue.

PRESIDENT'S ADDRESS

"This has been a very successful year," declared President Funk in his presidential address which brought the annual meeting to a close. "I don't take any credit for it at all," he continued; "the credit goes to all of those who arranged the programs or participated in them, and to the large number of members of the various committees that carried on their work so faithfully in spite of the great deal of personal hardship . . , on account of present-day difficulties."

Speaking of the Institute's meeting program during the year, Doctor Funk said there was quite a wide expression of opinion that it would not be patriotic to continue the meetings during the war. There is pretty definite proof that we were right in continuing these meetings, he asserted, because the attendance has been greater than before the war. Doctor Funk attributed the increased attendance partly to the fact that so many members were thrown into entirely different work from what they were accustomed to and that they therefore needed the new information they could obtain from the Institute's technical meetings.

Paying tribute to the work of the District organizations and the Sections, Doctor Funk expressed the opinion that we as an Institute have every reason to be proud of the work that the Sections are doing. He mentioned also the assistance that the District organizations have given the Sections in arranging for speakers and topics for Section meetings. He also expressed his gratification that many of the Sections are co-operating in local activities with other local engineering associations. He mentioned the war-production clinics that had been held in the various parts of the United States as outstanding examples of local co-operative projects.

Discussing student activities, President Funk urged that the programs of all national and District Institute meetings include a session for the students. Some of the boys put their elders to shame in presenting papers, he declared, adding that they also know how to handle questions during the subsequent discussion. He urged that the students also have a place on the social part of the program.

As a concluding thought, Doctor Funk emphasized the need for engineers to devote increased attention to human relationships, stating that when we "begin to deal with human relations, we are dealing with something that doesn't fit any type of mathematical formula," and pointing out that in some of these human relationships we must sacrifice efficiency to some extent if we are going to preserve freedom. "To overcome some of these difficulties," he concluded, "we must be prepared by a broader outlook, if we can, so that we do not hold too closely to our more technical performance, so we don't hold our technical performance so close to our eye that we lose the entire landscape of human needs and desires and hopes and all characteristics that make life worth living."

Delegates' Conferences at St. Louis Feature Expanded Clinic Plan

Four sessions comprised the program of conferences for officers, delegates, and members at the AIEE 1944 summer technical meeting in St. Louis, Mo., which included one combined conference and three so-called Sections clinics. Initiated at the 1943 conferences, the success of the clinic plan led to its expansion to include three clinics this year as compared with the two held last year. Delegates from the larger Sections, the smaller Sections with concentrated membership, and the smaller Sections with scattered membership, respectively, discussed their Section operating and management problems in the three parallel clinics.

By grouping the representatives of Sections of similar type, Section operating problems common to each of the three classes of Sections could be discussed more advantageously than in one combined clinic. This year's clinics were outstanding for the number of delegates participating actively in the discussions. The plan used last year of having specific subjects introduced by "panel leaders" followed by scheduled and unscheduled delegate discussions from the floor was followed again this year.

At the combined conference, there were scheduled talks and some delegate discussion on a variety of Institute activities of interest to all Sections. A skit depicting in dramatic form some of the operating problems faced by many of the Institute's 73 Sections brought the combined conference to a close.

The success of this year's conferences amply justified the long hours of thoughtful advance planning on the part of the various members of the Sections committee and especially its energetic and capable chairman, G. W. Bower. Summarized reports of the proceedings at the four conferences follow.

Combined Delegates' Conference

Scheduled talks on various phases of Institute activities, followed by informal discussion from the floor, comprised the major portion of the Tuesday afternoon combined conference of officers, delegates, and members. Section and District activities were covered by President Nevin E. Funk and National Secretary H. H. Henline, respectively. Chairman G. W. Bower reported on the activities of the Sections committee during the year, and chairmen T. F. Barton (finance), J. H. Pilkington (membership), and F. A. Cowan (prize awards) spoke on aspects of their respective committee activities that are of particular interest to the Sections. A plan of action whereby local engineering organizations may co-operate on projects of local interest was outlined by Everett S. Lee (F '30), chairman of the Engineers' Council for Professional Development. R. M. Pfalzgraff (M '41) of Wilmington, Del., vice-chairman of the Sections committee, presided throughout the combined conference.

Following the formal portion of the program, a skit entitled "The Rendezvous Arduous" was given, representing the executive committee of the AIEE "Utopia" Section in session. Problems faced by many of the executive groups of the Sections were portrayed in effective and sometimes amusing fashion. C. S. Schifreen, of the Philadelphia Section, acted as chairman of the Utopia Section. Other members of the "executive committee" were: F. J. Berger (A '27) vice-chairman (papers and meetings); A. C. Muir (M '39) secretary-treasurer; W. R. Clark (A '37) past chairman; W. F. Henn (A '41) (entertainment); L. E. Howard (A '40) (publicity); G. W. Bower (M '40) (membership); M. D. Hooven (M '30) (Subsection).

SECTION AND NATIONAL ACTIVITIES

Relationship between AIEE Section and national activities was the subject of the initial talk of the conference, given by President Funk. Declaring that "Section activity is really the lifeblood of the institution as a whole," he said that "as a national organization we really depend upon the Sections almost wholly to make the Institute a going aggressive organization."

Pointing out that the total attendance at local AIEE meetings far exceeds the total attendance at its national meetings, Doctor Funk declared that there is an even greater volume of information contained in the technical papers spread before the members at the local meetings than in the papers produced through the activities of the national committees. He also called attention to the splendid opportunities that the Sections have to co-operate with the Student Branches in their respective localities and at the same time bring the students in contact with men actively working in industry.

Emphasizing the importance of co-operation in the Sections, he said that "the only way a satisfactory conclusion of any effort is attained is by co-operative work," adding that "you cannot obtain the ability to co-operate by reading books. The only way you become proficient in that is by actually practicing it."

Referring specifically to the activities of the Sections during the war period, Doctor Funk pointed out that they have been more active than in previous years even though nearly everybody connected with the Sections has been busier than at any previous time. The work of the Sections has improved each year, he concluded, and "there isn't any question whatsoever that it is going to get better and better in the future."

PRESIDENT-ELECT POWEL SPEAKS

In his brief remarks, President-Elect Charles A. Powel emphasized the importance of co-operative work between the AIEE Sections and other local engineering organizations. Characterizing the American Engineering Council as a noble experiment that failed, he declared that "we just started at the wrong end. We were trying to get all of

the associations together at the top whereas we should have been working down at the foundation." He expressed the opinion that the Sections realize that co-operation with other societies must be carried on locally.

DISTRICT ACTIVITIES

The District organizations fit in between the Sections and Branches and the national organization of the Institute, pointed out National Secretary H. H. Henline in his talk on this subject. "Although District activities have been going on quietly and effectively for a good many years, perhaps that very quietness and effectiveness have caused people to overlook them," he continued.

Outlining the circumstances leading up to the establishment of the Districts, Mr. Henline told how a special committee recommended in 1919 that there should be Districts throughout the United States with a vice-president in each District. With the adoption of this plan there began in 1920 the procedure now followed in which the country is divided into nine districts with Canada comprising the tenth. A vice-president is elected in each District to be in charge of the activities in his District. These vice-presidents are nominated entirely by the members of the executive committee in their respective Districts.

Initiation of the District plan started a chain of events that is still in progress, Mr. Henline continued, because occasionally we still have some further development connected with District activities. He related how the board of directors authorized travel-expense allowances for the District executive committees to meet in 1923, and for the vice-presidents to visit the Sections in their Districts in 1924. A little later, travel allowances were made for the vice-presidents to visit the Branches in their Districts. In 1925 a plan was adopted for the holding of District meetings as distinct from both national and Section meetings.

Travel allowances for District student conferences first were authorized in 1926. The success of the first conference led the board to authorize travel allowances for a student conference in each District each year.

The District activities are carried on by the District executive committee, Mr. Henline continued. This committee now consists of the District vice-president, District secretary (appointed by the vice-president), the chairman and secretary of each Section in the District, the vice-chairman of the national membership committee representing the District, and the chairman of the District committee on student activities. Each District executive committee sets up a District co-ordinating committee, including some of the members of the executive committee but making a smaller committee which is in a better position to take quick action.

Reporting that a total of 49 District meetings have been held, Mr. Henline stated that the District-meeting plan has been highly successful. It is intended that these meetings be of a rather local nature so that the members in a District may concentrate on the subjects in which they are especially interested. In addition, it has become customary to give the students a prominent place in these District meetings, and that plan has been highly successful.

The District organization and activities have developed over a period of 24 years from actual experiences, Mr. Henline concluded. In many cases some experiment has been carried out successfully and then became part of the regular procedure. The District organizations have made it possible for members almost anywhere in the country to take a larger part in Institute affairs than they might otherwise and have contributed greatly to the development of the Institute.

G. W. Bower (M '40) chairman of the AIEE Sections committee (left), and (right) C. S. Schifreen (M '43) chairman of the AIEE "Utopia" Section. A skit depicting a typical meeting of the Utopia Section executive committee was given at the close of the combined conference of officers, delegates, and members

"WILL YOU HELP?"

In his talk, Mr. Lee first told how the Engineers' Council for Professional Development, joint agency of eight national engineering societies including AIEE, is endeavoring to enhance the professional status of the engineer, and second described a booklet entitled "Will You Help?" which outlines how the local organizations of these societies can co-operate to further this effort. Copies of the booklet were distributed to all those present.

Describing how the objectives of ECPD are carried forward by four standing committees —student selection and guidance, engineering schools, professional training, and professional recognition—Mr. Lee outlined some of the principal accomplishments of those committees. News reports of these activities have appeared from time to time in *Electrical Engineering* over the past several years.

Urging all of the delegates to take home and use their copies of the booklet "Will You Help?", he indicated how local action might be taken in the manner outlined in the booklet by local engineering groups leading to recommendations to the ECPD participating societies. These recommendations may then be passed upon by the societies, and in that way co-operative action may be taken on a national basis.

SECTIONS COMMITTEE ACTIVITIES

Promotion of the organization of Subsections and technical groups constituted one of the most important activities of the Sections committee during the past year, reported Chairman George W. Bower. Four new Subsections were formed, making a total of ten now in operation; 27 technical groups are now functioning, and several Sections were reported as considering the advisability of forming such groups. The project of organizing Sections in South America and in the West Indies, which was discussed at some length during the 1943 conference, has been held in abeyance because of the war.

"Subsection operation is gaining in popularity since the distribution of the folder 'Subsections' in March 1943," Mr. Bower stated. "The Sections committee is individually following 26 locations in the territory of the Sections where there are possibilities of successful Subsection operation. Many Sections have possible locations for Subsection operation, but in some cases the number of present Institute members at the location is too small for the organization of the Subsection. A survey of the territory may reveal many potential members, especially if local Subsection meetings are provided." He then cited the experience at Great Falls, Mont., where there were only five members. A survey revealed enough prospective members in that area to justify the formation of a Subsection, and the chairman of the Montana Section recently reported that in the near future there will be a very active Subsection at Great Falls. Mr. Bower urged other Sections to survey their territory for similar Subsection possibilities.

In order to assist in the further development of technical groups by the Sections, the Sections committee prepared a folder on that subject and circulated it early this year to all Section officers. In reporting on this activity, Mr. Bower emphasized the difference between the Subsections and the technical groups. The former provide for geographical diversification of Section activities, whereas the latter provide for diversification of technical subject matter discussed at meetings.

During the past year the Sections committee has endeavored to develop closer co-operation with the vice-presidents and chairmen of the national committees, Mr. Bower further reported. He urged that this effort be continued and suggested that the national technical committees could actively encourage the organization of technical groups in the various branches of electrical engineering through the co-operation of their committee memberships.

SECTION FINANCES

A brief outline of the Institute's general financial situation, with particular emphasis on Section finances, was prepared by Chairman T. F. Barton of the finance committee. As Mr. Barton was confined to his hotel room by a severe cold, his report was presented by W. R. Smith, Jr., member of the finance committee. The report centered around three charts showing the allocation of Institute receipts, expenditures, and investments, which were displayed prominently at the front of the room.

A chart on investments showed that the Institute now holds securities of the following classes:

Government bonds	$200,000
Public-utility bonds	11,000
Railroad bonds	23,320
Railroad preferred stocks	14,100
Common stocks	70,500
Gross total	$324,920

The chart depicting the sources of the Institute's revenue indicated the following:

	Per Cent of Total
Membership dues	67.1
Advertising	19.0
Entrance and transfer fees and student enrollments	7.3
Miscellaneous	4.3
Investment returns	2.3
	100.0

The Institute's expenditures were indicated on the third chart which showed:

	Per Cent of Total
Publications	28.2
Headquarters expenses	21.2
Sections	16.1
Joint activities	12.0
Meetings	6.0
Committees	4.3
Student activities	3.8
Traveling expenses	3.7
Yearbook	2.7
District expenses and prizes	2.0
	100.0

Mr. Smith explained that the Sections appropriation embraces a flat amount of $175 for each Section plus an allowance of one dollar for each active member in the Section territory on August 1 of each fiscal year. That item includes also: the cost of traveling expenses of Section delegates to summer technical meetings; stationery and supplies furnished by the headquarters office to the Sections; and a proportion of headquarters' salary expense chargeable to Sections. The item for meetings covers three national and two District technical meetings. Committee expenses comprise chiefly expenditures of the membership committee, technical committees, and the finance committee; Standards committee expenditures are not included since this activity is substantially self-supporting. "Traveling expenses" include principally the traveling expenses of Institute officers including the board of directors, president, vice-presidents, national nominating committee, and Institute representatives. The last item listed includes traveling expenses for District executive committees plus the cost of District prizes awarded, in addition to the national prizes.

Following the presentation of this report there were several informal discussions from the floor. W. H. Taylor, chairman of the Denver Section, reported that 73 per cent of that Section's expenditures are for meeting notices and publicity; 12 per cent covers the meeting expense and 15 per cent "executive" expense. These proportions perhaps are typical of many Sections that print and circulate their own meeting notices. W. R. Hough of the Cleveland Section said that the Denver Section experience paralleled that of the Cleveland Section until about three years ago when the Cleveland Technical Societies Council was organized. That Council is made up of about 26 societies and it publishes a weekly bulletin which carries all meeting notices and is largely self-supporting through paid advertising. This has reduced the meeting-notice expense of the Cleveland Section to about 13 per cent of the total Section expenditures, leaving a larger proportion that can be devoted to meetings. P. L. Johnson, Los Angeles Section, related how that Section's expenses had been greatly increased in providing for the rapidly growing aircraft division of the Section. In the preceding two years, the increase in Section operating expenses was respectively $200 and $460, largely to provide for increased printing and mailing of meeting notices. These notices were sent to both new members and many prospective members chiefly in the aviation industry.

MEMBERSHIP ACTIVITIES

"The Section committees are the real backbone of the whole membership effort," stated J. H. Pilkington, chairman of the membership committee in speaking to the delegates on this subject. He outlined the organization and functioning of the national membership committee and the Sections membership committees, discussed some of the most important aids to membership work and some of the results achieved, and finally posed some of the problems that remain to be solved.

"Altogether it is estimated that over 1,000 men are engaged in Institute membership work," declared Mr. Pilkington, who explained that the national membership committee is composed of a chairman, a vice-chairman, a secretary, approximately ten members-at-large, ten District vice-chairmen, and the chairmen of the Section membership committees ex officio. The national committee serves as a clearing agency for all directives and is set up to aid the Section committees in many ways. The vice-chairmen direct operations in their respective Districts, but direct access to the national chairman by the Section membership chairmen is encouraged. "We view the work of the Section membership committees as not only that of obtaining new members but also that of holding existing members, especially those who may be wavering in their interest in the Institute," Mr. Pilkington stated.

"There are two kinds of aids which are and should be available for maximum effectiveness in Institute membership work. The first might be termed mechanical aids and the second psychological aids." Mr. Pilkington then described some of the mechanical aids available which include a membership committee guide, available from Institute headquarters upon request by the Section membership chairmen, and conveniently sized booklets prepared from time to time containing general information. The latest such booklet, entitled "Accomplishments of the AIEE in the Engineering World," was distributed to the entire membership in the fall of 1943. Additional copies are available from headquarters.

Among the so-called psychological aids, Mr. Pilkington mentioned as important our long record of technical accomplishments and the serious purpose back of them; good fellowship and sincere hospitality; and changes in organization setup to meet the changing demands and wishes of the membership. Among the little things that assist in this direction are the display of Member and Fellow diplomas by members in those categories and the simple expedient of inviting nonmember engineers to Institute meetings.

In regard to results, Mr. Pilkington stated that the net increase in Institute membership during the past two years totaled 2,500 or over 13 per cent, bringing the membership on April 30, 1944 to an all-time high of 21,407. This net increase came about from approximately 4,300 gross additions to the membership rolls. The 1,800 members who fell by the wayside include 1,200 dropped for nonpayment of dues. The latter, Mr. Pilkington declared, present a challenge that represents one of the problems to be solved. Another problem has to do with transfers to higher grades of membership. Although the Institute has a national transfers committee, the Section membership committees can assist in this effort.

Delegate discussions from the floor were given by Carl Evans, secretary of the Georgia Section, M. D. Hooven, New York Section and R. C. Gorham, chairman of the Pittsburgh Section. A membership campaign carried on largely by mail which netted the Georgia Section an increase of 32 per cent in its membership in approximately two months was described by Mr. Evans. Qualified prospects were uncovered by member recommendations. These prospects then were written personal letters telling them they had been nominated for membership in the AIEE and that they had been investigated and found to be qualified, and enclosing a return postcard by which additional information could be obtained. Names of interested prospects were circulated in mimeographed form to the entire membership with the suggestion that if any member were personally acquainted with any of the prospective members and could serve as a reference that he get in touch with the prospective member and offer his services as a reference. This procedure is believed to have been an assistance.

Mr. Hooven told how the New York Section carries on its membership work with a committee comprising 130 members and auxiliary members totaling some 200 so that there are a total of between 300 and 400 members doing membership committee work in the New York Section. During the past year 430 new members were obtained, or a little over ten per cent increase in membership. Prospects are uncovered by letters to the entire membership, from cards signed by those attending Section meetings with spaces for notations by members and nonmembers, and through educational courses. Nonmembers are charged double the member fee to take educational courses operated by the Section, with the provision that those who join the Institute later will be refunded the additional charge. About 100 new members have been obtained through that channel. Prospects are followed up personally, either by letter, telephone, or personal call.

The Pittsburgh Section follows some of the same practices as the Georgia and New York Sections, reported Mr. Gorham. One source of new members that has been very fruitful in normal times, however, is providing almost no new members at the present, namely, the various engineering schools in that Section's territory. This partially accounts for the fact that the Pittsburgh Section registered only a five per cent increase in membership during the past year.

Closing the discussion of this topic, Mr. Pilkington presented membership increase statistics for the year as follows:

	Per Cent
Increase in total membership	13
Increases by Districts	
Northwest (9)	19
Southwest (7)	18
Southern (4)	18
Pacific (8)	15
New York City (3)	15
Canada (10)	13
Great Lakes (5)	13
North Central (6)	11
Middle Eastern (2)	10
Northeastern (1)	10

Larger Sections equaling or bettering the national increase:

Milwaukee	23
Seattle	21
St. Louis	20
Los Angeles	17
Boston	14

Smaller Sections (scattered membership) that equaled or bettered the national increase:

Montana	40
East Tennessee	39
Arizona	24
Tulsa	22
Central Indiana	20
West Virginia	16
Urbana	16
New Mexico–West Texas	15
Alabama	14
Ithaca	13
North Carolina	13

Smaller Sections (concentrated membership) that equaled or bettered the national increase:

Mexico	200
San Diego	34
Montreal	33
Memphis	30
Georgia	30
South Bend	28
Houston	26
Wichita	21
Spokane	20
Dayton	20
Portland	18
Fort Wayne	17
Kansas City	17
Akron	16
Syracuse	14
Cincinnati	14

SECTION PAPERS AND PRIZE AWARDS

"A review of the prize-award practices to determine what if any changes in the setup appear desirable" has been in progress for some time, declared F. A. Cowan, chairman of the committee on prize awards, who added that one conclusion reached so far is that the Sections are quite an important factor in the prize-award setup. He explained that the Institute each year offers $1,500 in prizes, $500 of which goes for national prizes and the remainder allotted equally among the ten Districts. Experience in the past six years has shown that only about one third of the available $1,000 in District prizes has been used, whereas essentially all of the national prizes have been awarded. Many suggestions have been offered, Mr. Cowan said, as to how this situation should be remedied, and a poll of the vice-presidents' opinions seems to indicate that perhaps the Sections are not aware of the prize possibilities.

Pointing out that the officially approved technical papers on the programs of the national meetings automatically are entered in the national prize competition, Mr. Cowan explained that the Section papers also may compete, but in order to do so they must be entered specifically for that purpose. Likewise District-meeting papers are automatically considered for District prize awards, but the Section papers again must be submitted specifically in order to compete. He urged the Section delegates to take the necessary steps to enter Section papers in both the District and national competitions. A further advantage of submitting the papers would be that they would be reviewed with the idea of possible publication.

In regard to publication, F. A. Lewis, AIEE acting editor, reported that 12 Section papers had been published in the general-interest section of *Electrical Engineering* in 1943; in 1944 to date 8 Section papers have been accepted, three of which are still to be published. Considering that the Institute now has 73 Sections, and that only 7 Sections are represented among these papers published in 1943 and 1944 to date, Mr. Lewis expressed the opinion that there must be many Section papers that would make good material for publication in *Electrical Engineering* but that are not made available for that purpose. He urged the Section officers to submit their papers for publication, pointing out that by so doing they could serve a twofold purpose: (1) help to obtain more material for *Electrical Engineering*, thereby improving the over-all quality of the articles published therein; and (2) achieve recognition for their Sections through national publication of their papers.

The Philadelphia Section has a separate publicity committee which has as one of its duties arrangements for submitting to headquarters papers for publication in *Electrical Engineering*, reported A. C. Muir of that Section. When a paper has been presented before the Section and is considered to be exceptionally good, the publicity committee asks the speaker for copies to send to headquarters. If the paper is considered to be prize material, extra copies are submitted for that purpose. Mr. Muir reported that during the past two seasons, the Philadelphia Section had submitted to headquarters six papers, four of which had been accepted for publication, and efforts are being made to have two more prepared that were presented originally before technical-discussion groups.

Larger-Sections Clinic

R. M. Pfalzgraff of the Philadelphia Section, vice-chairman of the Sections committee, presided, and W. F. Henn of the Philadelphia Section acted as secretary. The larger Sections clinic was supplemented by an advisory panel group which opened discussion on the various scheduled items. Members of this group were: R. V. Shepherd, Schenectady Section, who conducted the discussion on meetings and programs; R. G. Warner, Connecticut Section, AIEE director and chairman of the Student Branch committee, student activities; R. C. Gorham, chairman-elect and present secretary of the Pittsburgh Section, fellowship; W. R. Clark chairman of the technical groups committee of the Philadelphia Section, technical groups and Subsections.

MEETINGS AND PROGRAMS

Mr. Shepherd said that the Schenectady Section, because of the large number of technical societies in its city, was faced with a problem of getting regular attendance at AIEE meetings. The Section had solved this problem by designating Thursday night as electrical-engineers' night, and the other groups had co-operated by not scheduling their programs on Thursdays. The Schenectady Section is a member of the Schenectady Engineering Council which co-ordinates the activities of its respective member societies in order to make all meetings of general interest available to the entire group. Each member group in the council is allotted one or two general-interest meeting nights and several other meeting nights to cover technical subjects in its own field. The Schenectady Section has continued co-operation with the Pittsfield Section through its joint prize paper contests for younger engineers.

J. W. Bishop, chairman of the Michigan Section, announced that his Section had sponsored five round-table discussions during the past year, two of the meetings being held in Jackson and arranged by the Jackson members of the round-table committee. The round-table meetings are concerned with solving local problems.

C. A. Smith reported that the San Francisco Section has instituted a special shipyard group. An average of 80 persons attends these meetings. Eighteen new AIEE members have been obtained through the shipyard group and the mailing list includes about 220 nonmembers. Subjects discussed at these meetings included arc welding, public-address system and gyroscope-compass pilot indicator, interior communications and marine cable in wartime, planning the world we want, marine electric equipment under the auspices of the Navy, and designing and operating ships' electric systems.

Printing and mailing costs for announcements of meetings and methods for financing these expenses were discussed.

FELLOWSHIP

Mr. Gorham introduced the subject of fellowship and suggested the following topics for discussion: a fellowship committee, social periods, an attendance committee, identification cards, greeting letters, weekly get-acquainted luncheons, and student and member banquets.

W. R. Hough of the Cleveland Section reported that his Section had a reception committee and an attendance committee and had been successful with identification badges, social periods following the meetings, and its annual ladies' dinner. M. W. Pullen, chairman of the Maryland Section, stated that that Section had had unusually good attendance and attributed this in part to the dinners which preceded their general sessions.

W. F. Henn declared that the Philadelphia Section had dinners and social periods in connection with their meetings. This Section reported success with the use of identification tags which they placed in a grand-prize bowl for prize drawings at the end of the year.

M. D. Hooven, New York Section, cautioned against the danger of a Section's making its meetings overtechnical and not allowing time for a social period. The New York Section gained a lot of younger men who are interested in technical matters but lost older engineers because of inadequate fellowship activities.

STUDENT ACTIVITIES

Mr. Warner urged that if Sections have committees to co-ordinate Branch interest, they should place on these committees the outstanding men in their Sections who will be an inspiration to the student members. He suggested Sections having annual dinners at which students are special guests and sit with men who are leaders in the particular fields in which the students are interested. He cautioned against a Section's dropping student activities because of a dearth of students resulting from the war and said that the student organization should be kept going. "When there are one or two students, those have to be the leavening for the one or two coming back from the service."

Nevin E. Funk, president AIEE, advocated the Section being the guests of the students. "It really makes them feel, since they are hosts, that they are part of the major organization," he pointed out. Section members interested in the student organization should

make sure that older members turn out in good enough force so that the students would not feel slighted, he cautioned.

TECHNICAL GROUPS AND SUBSECTIONS

Mr. Clark outlined the nature of technical groups and Subsections and the benefits the Section derives from them and told how they are organized. There are three types of discussion group meetings, he explained: short talks by one, two, or three individuals on the subject of discussion and general discussion following; panel discussions with experts in the field to answer questions from the audience, and the single formal talk followed by discussion from the floor. Chairman Pfalzgraff pointed out that the larger Sections incline toward subdivision into technical discussion groups, whereas the majority of Subsections are sponsored by the smaller Sections. As of June 26, 27 technical discussion groups were reported in operation in 13 Sections of the United States—eight of them large Sections; but of the ten Subsections functioning, only four derive from larger Sections. Subsection possibilities are being considered in the Michigan Section in Bay City which is 106 miles from headquarters and has a population of 48,000. San Francisco reports two Subsection possibilities one in Sacramento, 99 miles from Section headquarters with a population of 106,000 and 11 AIEE members; and Laro and Mare Island Navy Yard, 35 miles from Section headquarters with a population of 20,000 and over 34 AIEE members. Seattle Section has a possibility in Tacoma, Wash., 31 miles from headquarters with a population of 109,000 and 31 AIEE members.

P. L. Johnson, Los Angeles Section, described the formation of the aircraft and electronics divisions in his Section. Because of the widespread aircraft industry in their area, the aircraft engineers were considering the formation of a separate technical society. In the interests of unity, the AIEE Section persuaded the aircraft people to make use of the already established AIEE organization for promoting their technical meetings. A recognized leader for the group was appointed by the Section executive committee, and four meetings were conducted in 1942–43. During the 1943–44 season the aircraft group held five meetings with an average attendance of 208. The increase in national membership in the Los Angeles Section in the last two years was 84. At the Los Angeles technical meeting, August 29–September 1, of the 16 technical sessions 13 will be devoted to aircraft problems, and more than 50 technical papers on this subject will be presented.

Mr. Hooven said that the New York Section, faced with the problem of serving a large concentrated membership in a restricted area, has become a sort of holding company for five major technical groups, some of which were established as early as the late '20's. Each group holds individual meetings, chooses its own officers and committees, and shares the same membership of 4,000. Each group meets jointly with other organizations of similar interests such as the Institute of Radio Engineers, American Society of Mechanical Engineers, and Illuminating Engineering Society. The New Jersey members, opposed to forming a Subsection, are represented by a special-activities committee which functions autonomously. The year's program for the New York Section includes 20 Section meetings, about 100 lecture meetings as part of educational courses, and many committee meetings. The technical groups have become operating "Sections" in the New York area.

C. H. Cutter of the Seattle Section reported that Tacoma which had been mentioned as a possible location for a Subsection preferred to remain in the Seattle Section; one Section meeting was sponsored by the Tacoma group each year. He also stated that Seattle Section had considered forming an aircraft group for the Boeing Company electrical engineers, but the Boeing Company group preferred to have their own meetings and remain part of the general Section; one Section meeting is turned over to the Boeing group also each year.

F. C. Barnes, chairman of the Toronto Section, announced that the Hamilton discussion group had blossomed into a Subsection last spring and has 55 members. The Ottawa Subsection has 38 members, and the Frontier group has formed a Subsection which has been in operation for one year. Toronto also has another group of 38 members 90 miles from Section headquarters which is expected to develop into a Subsection very soon. Mr Clark described the formation of the Wilmington Subsection of the Philadelphia Section. Mr. Smith stated that San Francisco is considering the possibilities of a Sacramento Subsection, but certain problems must be solved first. A common problem of both Section and Subsection activity is that of financial support; publicity accounts for the largest expenditure in almost every instance and is the most important factor in promoting successful meetings.

AFFILIATED SOCIETIES AND CIVIC AFFAIRS

C. M. Lovell, St. Louis Section, described the activities of the joint council of the Associated Engineering Societies of St. Louis, formed in 1914 and consisting of three representatives each of the Engineers' Club of St. Louis, the local sections of the various national engineering societies, and the American Welding Society. The Council promotes participation in civic affairs and has worked on the municipal smoke-abatement campaign and the registration of professional engineers in Missouri. Currently, a committee of the council is meeting with the Chamber of Commerce and other civic organizations to consider postwar problems and planning. The council is financed by an annual assessment not to exceed ten cents per member for the membership of the societies.

Mr. Hooven, representing the AIEE subcommittee on civic affairs, declared that one of this committee's aims is the espousal of local engineering councils interested in effecting greater public welfare and the promotion of national and sectional programs in the public service. W. R. Hough of the Cleveland Section described the Cleveland Technical Societies Council which has its headquarters in the building owned by the Cleveland Engineering Society; provides a permanent meeting place for each of the affiliated societies; and issues a weekly self-supporting bulletin to handle publicity stories, notices of meetings, and items of mutual interest.

In the Milwaukee Section, according to Ralph H. Earle, chairman, participation in civic affairs is supervised by the Engineering Council through a civic-affairs committee. Public-service projects such as studies of the erosion of the shores of Lake Michigan are conducted by means of inspection trips and reports of the observation.

Smaller-Sections Clinic—Concentrated Membership

G. W. Bower of the Philadelphia Section, chairman of the Sections committee, presided at the smaller Sections clinic, concentrated membership, and C. S. Schifreen of the Philadelphia Section acted as secretary. Members of the advisory panel group for this clinic were: E. T. Mahood of the Kansas City Section, AIEE vice-president, District 7, member and last year's chairman of the Sections committee; Walter Criley, Rochester Section; Everett S. Lee of the Schenectady Section, member of the Student Branch committee and chairman of the Engineers' Council for Professional Development; P. L. Alger, Schenectady Section, chairman of the subcommittee on engineers' participation in civic affairs.

MEETINGS AND PROGRAMS

Mr. Mahood introduced the subject of meetings and programs and outlined the various points to be discussed under this heading. He stressed the importance of a Section developing programs particularly appropriate for their own members in their own part of the country, the desirability of planning ahead for a year's program, the proper timing of meetings, and the importance of a meeting starting on time.

C. P. Robinson, speaking for the Mansfield Section, said that his Section had an unusual situation in that 33 of its 80 members were located in Galion, 17 miles away, and all were identified with the same company, a telephone manufacturing company. The Section program is set up on the basis that two of the six officers are selected from the members in this company each year, and two of the four technical sessions in a year are held at Galion and directed toward the interests of the telephone men.

F. L. Lawton said that the new Montreal Section, in order to attract both the older and younger members, had held a daytime annual meeting which started at three o'clock in the afternoon at a country club and included golf, dinner, business meeting, entertainment for the ladies, and movies.

V. F. P. Sepavich said that the Worcester Section had had to make its meetings appeal to the members from a social standpoint and had also selected subjects of popular wartime interest to attract a large attendance.

T. E. Rodhouse reported that the Pittsfield Section had about 250 national members and 1,500 local members, as a result of the popular general-interest lecture service which the AIEE Section conducts there. This Section also conducts a series of technical lectures. President Funk praised the experiment of the Pittsfield Section and said that smaller communities presented a good opportunity for an AIEE Section to make itself a going and active concern in the community in this fashion. Mr. Mahood suggested local membership as a possible means of a Section's retaining the interest of younger AIEE members who drop out because for a time they cannot afford to continue their national membership. C. W. Lethert, Minnesota Section, said that his Section had discovered it had a fertile

field for local membership, and that as a result of this its local membership had jumped from 12 to 67 this year. Mr. Criley stated that the Rochester Section had set up its own rules for local membership, that an applicant must have 600 hours of electrical education beyond high-school level or must have a minimum of five years experience in electrical work—maintenance or construction—and must be a foreman, subforeman, or group leader. Local members are allowed to serve on committees, but they cannot vote nor hold office.

FELLOWSHIP

Mr. Criley introduced the subject of fellowship and said that the Rochester Section had built its fellowship around stag parties and bowling, preceding a technical session had dinner for the speaker to which anyone might come, sent new members letters of welcome, and held weekly luncheons one month in the year in co-operation with the Rochester Engineering Society.

J. W. Gehrke, secretary of the Dayton Section, reported that his group, a new Section, had had unusually good success with celluloid name buttons at their meetings. J. R. Morton, Memphis Section, declared that his Section uses attendance buttons and awards attendance prizes from a drawing. The winner of an attendance prize must identify by name everyone at his table before receiving the prize.

B. H. Bell stated that the New Orleans Section believed that if you give a member a job to do he is always a better member. Therefore, all of their committees are large, and the committee chairman turns over at least one meeting to each committee member. This year each meeting will be in charge of two members of the program committee, one experienced member and one younger student member; the student member will be responsible for the meeting and will be advised by the experienced member. The New Orleans Section also has a prompt-attendance prize, and all members and guests who are present before the meeting starts participate in the drawing. W. T. Johnson, chairman of the San Diego Section, said that his Section succeeded in keeping up the attendance of its older members by awarding past presidents gold buttons to wear at meetings instead of the celluloid button worn by other members.

President-Elect C. A. Powel pointed out that the Institute is really conducted in the Districts and the Sections. "This trend toward decentralization is worth while," he declared, "and should be pushed. When the Institute reaches a membership such as ours has of nearly 22,000, we at the top of the association cannot hope to continue to direct it entirely from the top. The men that have to run the Institute are you fellows that are running the Sections."

STUDENT ACTIVITIES

Chairman Bower, introducing Mr. Lee who led the discussion on student activities, said that only 20 per cent of the AIEE Sections have student-activities committees or committees of similar nature. Mr. Lee urged the necessity of Sections co-operating in student activities even though they are located where there are no Student Branches. When students are graduated, he pointed out, they move to other localities where there are industries but possibly no Student Branches, and it is up to the Sections of the students' new localities to contact them and keep in touch with them until they become Associate members. Mr. Mahood stated that in the South West District there are 14 Student Branches, one or more in every section of the territory with the exception of Wichita and that those Sections are very close to the Student Branches.

C. P. Knost, chairman of the New Orleans Section, said that his Section has co-operated with the Louisiana Engineering Society which takes in all four Founder Societies and some other engineers in creating a committee on student guidance. This committee has fostered talks by engineers to the high-school boys about engineering and appoints counselors for them. A. J. Allen said that the Cincinnati Section holds its meetings at the University of Cincinnati when the subject is of particular interest to students. At the June meeting three prizes are awarded to electrical-engineering students by the Section for work on their final theses.

W. E. Enns, secretary of the Portland Section, said that his Section entertained the students at a dinner meeting in the fall, and the students in turn entertained the Section at the closing meeting in May. The Portland Section offers a prize of one year's Associate membership for the writer of the best student paper. They have sponsored a Dutch Uncle scheme whereby a student interested in a particular phase of electrical work is given an engineer experienced in that line as a personal adviser. E. F. Lopez stated that the Mexico Section, faced with the problem of engineering students who did not speak English, had published a bulletin in Spanish which included two or three articles from *Electrical Engineering* translated into Spanish.

TECHNICAL GROUPS AND SUBSECTIONS

Introducing the subject of technical groups and Subsections, chairman Bower stated that there are at present 26 technical groups in operation throughout the country covering 11 subjects, and a large increase in number of groups is expected next year. Mr. Gehrke described a new technical group in the Dayton Section on electrical engineering and aeronautics which started in November 1943. The group has had four meetings, each one consisting generally of two half-hour papers and ten minutes of discussion. The meetings are attended by about 100 persons each.

Mr. Lethert reported that the Minnesota Section has one technical group on power which has been in existence about five years and is planning to establish a communications group in connection with the Northwest Bell Telephone Company where the Institute has at present only one national member. Mr. Enns announced that the Portland Section has had three technical groups for a number of years: transmission and distribution, communications, and an electrometallurgical and electrochemical group. This year the three groups have collaborated on inspection trips of shipyards, aluminum plants, and steel mills.

Mr. Criley stated that there are too many technical meetings in Rochester, and therefore the Rochester Section's two technical groups on power and communications which have been in existence about ten years have to compete with a great many other technical meetings. He cautioned that a technical group meeting should consist of a number of short prepared discussions rather than one long speech. Mr. Lawton, Montreal Section, described the formation of the new Ottawa Subsection which has held two meetings, one in March and one in April, with an average attendance of 40 persons.

Hezzie Clark, secretary of the Houston Section, and J. D. Mathis, chairman of the New Beaumont Subsection, described the formation of the new Subsection. Mr. Mathis said that a faction of the Subsection wished to take steps to form a new Section, and suggested the possibility of the Lake Charles area joining with them in this endeavor. The Lake Charles area is now in the New Orleans Section, although 250 miles from New Orleans but only 45 to 50 miles from the Beaumont Subsection. Chairman Bower cautioned against formation of Sections with too small a membership to carry on Section work effectively. He said that there are ten Subsections operating in the AIEE at present, four of which were started this year, and there are 26 locations where the operation of Subsections is being considered.

AFFILIATED SOCIETIES AND CIVIC AFFAIRS

Mr. Alger urged formation of affiliated societies' councils to promote engineers' participation in civic affairs. He cited the directory of the Technical and Scientific Society Council of Cincinnati, which lists all the engineers in the community with their job titles and addresses as a successful joint enterprise.

E. F. Lopez (M '18), Mexico Section, was the delegate who traveled farthest to the summer meeting. A familiar figure at summer meetings, Mr. Lopez reported that the Mexico Section had trebled its membership during the past year and that during the coming year it expected to double its present membership

Smaller-Sections Clinic—Scattered Membership

A. C. Muir, Philadelphia Section, secretary of the Sections committee, presided at the smaller Sections clinic scattered membership, and L. E. Howard of the Philadelphia Section acted as secretary. Advisory panel members were: G. R. Peirce, chairman of the Urbana Section, meetings and programs; V. P. Hessler, chairman of the Kansas City Section, fellowship, entertainment, and attendance; M. S. Coover, Iowa Section, AIEE director and member of the Sections committee, student activities; E. W. Schilling,

Montana Section, AIEE vice-president, District 9, and member of the Sections committee, technical groups and Subsections.

MEETINGS AND PROGRAMS

H. E. Pearson, chairman of the Lehigh Valley Section, described the manner in which meetings were handled in his Section which has an extensive area and scattered membership. The Lehigh Valley Section is divided into eight districts with a manager over each district. One meeting per year is held in each district, alternating between the four northern and the four southern towns. The managers of all districts are members of the meetings and papers committee. The chairman of this committee co-ordinates all papers and programs for the year.

H. A. Norburg, Tulsa Section, said that the membership of his Section is culled from a radius of 260 to 300 miles. No group is large enough to have a separate meeting, and so the Section tries to have one program of particular appeal to each group during the year. The average attendance per meeting is about 40 out of 90 members. The Eastern Tennessee Section reported that it has co-operated with the American Society of Mechanical Engineers in getting speakers, and thus had been able to get good speakers of national importance.

FELLOWSHIP

Professor Hessler, introducing the subject of fellowship described the machinery for getting acquainted which had been in operation in the Kansas City Section for the past six years. The Sections' popular dinner meetings draw an average attendance of 60 members from a membership of 150. Members of the American Society of Mechanical Engineers, the American Society of Civil Engineers, and other associations also are invited, and a more widespread interchange of ideas is effected. Fellowship among the members is strengthened by an annual spring social meeting to which wives and sweethearts of the members are invited.

Otto Meier, Jr. said that the North Carolina Section has only two meetings a year, but they are really one-day conventions. The Section covers a large area; members are scattered over the entire state, and they have to travel as far as 300 miles to attend meetings. They come in automobiles, several traveling together. C. R. Smith stated that the Arizona Section had the same geographic problems as Professor Meier's Section. They hold one meeting each month from September through May. A free dinner is given to the member who travels the greatest distance, but each member can have only one free dinner in a year. The Section has 48 national members and 45 local members.

Discussing the subject of local membership, A. F. Hartung, Kansas City Section, said that the Kansas City Section formerly had had a trial local membership with three dollars annual dues to try to interest candidates in joining the national organization. This local membership was limited to a two-year period per member. He stated that this experiment resulted in the increase in Section funds and some increase in national membership.

C. P. Allen said that his Section had joint boat rides, inspection trips, and meetings with mechanical and chemical engineers which contributed fellowship and interest in Section activities. Professor Hessler and G. B. Smedley, Chicago Section, mentioned the hobby night which the Illinois Subsection had for one of its social meetings, and said that it worked out successfully.

STUDENT ACTIVITIES

D. R. Hoopes said that the Utah Section urged its members each to sponsor a student and act as an adviser to him. A member from the Iowa Section stated that his section had gotten out a pamphlet on AIEE which is being distributed to students in high schools.

Professor Meier stated that the North Carolina Section's one-day meetings are attended by students, and they have a great deal to do in evolving the program. Students attend from Raleigh and Durham, and a prize of a year's membership and a complimentary dinner is given to the senior student presenting the best paper.

Mr. Hoopes said that his Section is a smaller one and has many social affairs which promote fellowship. The juniors and seniors of the University of Utah are student members of this Section and usually attend the social meetings 100 per cent.

A. B. Credle, chairman of the Ithaca Section, said that because of the year-round Naval training school now in existence at Cornell University, his Section had expanded its 9-month schedule to a 12-month one during the past year. The Section has about 200 members, 60 of them from the Naval training school at Cornell. The Section does not attempt to register students until they are in their junior year.

TECHNICAL GROUPS AND SUBSECTIONS

Professor Schilling, introducing the subject of Subsections and technical discussion groups, said that the Montana Section was starting a Subsection in Great Falls. There are two Institute members there, and the Section has contacted the electrical engineers of the Anaconda Copper Mines with the result that 15 applications for membership have been received. Engineers of other companies will be asked to join later. Professor Coover announced that the Zanesville Subsection of the Columbus Section had been quite successful in attendance, although many of its members have to travel 50 or 60 miles to meetings.

Professor Peirce said that his Section had had considerable success with its Illinois Valley Subsection which centers around Peoria. There are about 12 new members, and the Subsection has increased the national membership by about 27 or 28. Mr. Smedley said that the reason the Illinois Valley Subsection has doubled its national membership is that there is a very large local membership who are provided with speakers and kept informed of national activities at the nominal fee of one dollar a year membership.

E. H. Flath, secretary of the North Texas Section, stated that that Section, which covers 150 to 200 miles north and south and 700 to 800 miles east and west, would like to know how to go about organizing a Subsection. This Section has about 100 members in Dallas and 150 in Fort Worth and has a six-month meeting schedule but has received no requests for organizing a Subsection.

AFFILIATED SOCIETIES AND CIVIC AFFAIRS

Chairman Muir stated that of the 73 Sections in the Institute, 58 per cent are members of engineering councils. He pointed out the advantages of affiliated societies: use of the same dining room, employment of same secretary, joint bulletin, and reduced cost of circulation.

President Nevin E. Funk pinned the President's badge on President-Elect Charles A. Powel's lapel during the annual meeting. Here they chatted with two other members. Left to right: Mr. Powel; C. E. Stephens (M '22) Westinghouse Electric and Manufacturing Company, New York, N. Y., and past director; Doctor Funk; H. C. Forbes (M '30) Consolidated Edison Company of New York, N. Y.

Conference on Educational Problems and Student Counseling

More than 115 college teachers and engineers from industry who were interested in engineering education attended the conference on problems in engineering colleges and their effects in industry. The conference paper "Postwar Courses and Curricula in Electrical Engineering" was presented by the author, Professor R. G. Kloeffler (F '32) of Kansas State College. The paper, first of its kind to be presented before the AIEE, outlined the instrumentation by which the many phases of postwar educational planning for electrical courses could be effected. The analysis of the subject was well received, and the tenor of the discussion indicated that several engineering colleges were planning postwar training surprisingly close to the lines of thought expressed by the author.

An informal talk on "Interpretation of Present Hiatus in Engineering Education on Postwar Demands for Engineers" was given by J. L. Hamilton (F '21), Century Electric Company, St. Louis, who deplored the present condition whereby engineering education is practically deleted from the colleges, thereby leaving a dearth of incoming capable talent for the future services of industry. By calculations which involved figures based upon the war debt and the earning capacity of the nation, he arrived at 20,000 engineering graduates per year as the conservative number of engineering students which would be demanded from the colleges in the years directly following the cessation of hostilities, a number that is nearly double that of years preceding the outbreak of the war. To graduate this number of engineering students, he explained, would tax the teaching facilities of the colleges, and he proposed that industry itself should take an active part by cooperating with the colleges in the training of these engineers, and thus relieve to at least some degree the burden on the college faculties. The conclusions and recommendations of the speaker were supported in the ensuing discussion both by engineering teachers and by the industrialists. It was generally commented after the meeting that never had such support been expressed in the belief that industries, both small and large, should participate actively with the engineering colleges in providing for the students the best possible means of developing their talents to the highest attainable degree.

Following the conference, a clinic was held on college and high-school student counseling. A recommendation was made by G. W. Bower (M '40) chairman of the Sections committee, that each Section form a student-activities committee, such a committee to be composed of professors and members of industry and to include, if possible, graduates of colleges in the community. This committee would supply counselors for the high schools and the colleges, attend Branch meetings, and promote membership after the student finishes college.

The work of the educational committee of the St. Louis Section was outlined by T. L. Jones (A '41), and S. P. Shackleton (M '23) chairman of the student guidance committee of the New York Section, covered the activities in the metropolitan New York area working as a part of the New York engineers committee on student guidance. This joint committee of the Founder Societies has been developing since 1937. He recommended that student contacts be made early in the high-school-student's course so that he will be prepared adequately for entrance into an engineering college.

R. C. Gorham (M '31) secretary-treasurer of the Pittsburgh Section, discussed cooperation of Sections with Branches. Suggested ways and means consist of the promotion of prize paper and speaking contests, assistance in planning Branch meetings, sponsoring regional meetings at which the students assume a part, and the promotion of a social event as a means of introducing the students to practicing engineers.

L. M. Robertson (M '38) outlined work done by a committee as a member of the Denver (Colo.) Engineering Council. During the past year a "career night" was held at which students down to seniors in the junior high school were included. Members of the public school system have been enthusiastic over the results in the added incentive and enthusiasm that students receive.

General discussion emphasized that the counseling program does not have for its goal the recruiting of students for engineering but rather the providing of advice and information so that only those students who are particularly adapted will enter on an engineering career. The choice must be the student's, and all that these subcommittees can or ought to do is to present to the students what engineering consists of and to help them to make their decision by being available and ready to answer their questions.

Material for this report was supplied by Robin Beach (F '35) chairman of the AIEE committee on education, and S. L. Henderson (M '34), chairman of the subcommittee on high-school-student guidance, who presided over the conference and the clinic, respectively.

Conference on Experiences With Electric House Heating

A conference on experiences with electric house heating was held during the recent AIEE summer technical meeting in St. Louis, Mo., under the chairmanship of W. F. Ogden (M '41), chairman of the AIEE committee on domestic and commercial applications.

B. H. Martin of the Tennessee Valley Authority, Chattanooga, presented a paper "Electrical Heating of Small Homes in the Tennessee Valley" in which experience with electric house heating over a period of several years was reviewed. The application of electric heating in the area concerned has been almost wholly confined to what might be termed small homes. The average power consumption for 30 houses was shown to be 1.35 kilowatt-hours per cubic foot per season at a cost of 7.4 mills per cubic foot, on the standard TVA residential rate. It was emphasized that the cost of electric heat should not be compared with heating by other means on a "cost of fuel" basis alone, since electric heating increases usable space, effects savings in cleaning and redecorating, and is praised highly by those who use it. Usual installations in this area employ individual room heaters of the radiant-convection type, automatically controlled by thermostats built into each unit. This method of control improves the diversity of the load.

Following the presentation of Mr. Martin's paper, R. D. Sloan (M '28) presented comments on domestic electric heating at Grand Coulee Dam by Homer J. Dana of the State College of Washington, Pullman. It was recalled that during the building of Grand Coulee Dam many workers lived in electrically heated homes in Mason City, which was used by the State College of Washington as a laboratory to obtain unique data pertaining to average family requirements. When all factors which enter into a comparison between electric heat and other types of heating are taken into account, it was estimated that electricity at a rate of 6.3 mills per kilowatt-hour would compete evenly with 13,000 Btu coal at $8.50 per ton.

Experience with a heat-pump heating system was described in a paper "Reverse Refrigeration Applied to a New Haven Office Building" by E. Haviland Walton and Charles A. Williams (M '40), United Illuminating Company, New Haven, Conn. During the winter heat is extracted from water obtained from wells under the building and transferred to a water-circulating system. In the summer, heat is extracted from the water in the circulating system and removed by water obtained from the wells, to provide summer air conditioning. In this case the heat-pump system is feasible because of three factors:

1. Both heating and air conditioning are provided.
2. An adequate water supply is available from shallow wells.
3. Low-cost electric power is available.

It was shown that comparative annual fuel costs, with electricity at one-cent per kilowatt-hour, are:

Electricity using heat-pump system	$3,950
Anthracite coal	2,410
Bituminous coal	1,790
Number 6 fuel oil	1,660

Electricity also should be credited with the following intangible benefits:

1. Absolute cleanliness.
2. No fuel storage space required.
3. No chimney necessary.
4. Reliable supply of fuel.
5. Excellent year-round working conditions for operators.
6. Maintenance cost probably lower than for a fuel-burning system.

In subsequent discussion it was explained that the heating load was about twice the cooling load.

Material for this report was supplied by M. K. Brody (M '42) secretary of the committee on domestic and commercial applications, who acted as secretary of the conference.

Open Meeting on Domestic and Commercial Applications

An open meeting of the committee on domestic and commercial applications was held during the recent AIEE summer technical meeting in St. Louis, Mo., at which three reports of subcommittees were presented.

The report of the subcommittee on rural applications was presented by its chairman, C. H. Leatham (A '33). The part that electrical engineers must play in bringing electricity to rural areas was stressed in the report, which considered what the work of the subcommittee should be. Duplication of the work of other organizations or committees is to be avoided, and the task is seen to be one of studying work being done and following it up with suggestions from an engineering standpoint.

Wesley Weinerth (A '27) chairman of the subcommittee on wiring matters, presented a report which stressed the need for consideration of the domestic installation field and invited attention to the following points:

1. The general inadequacy of domestic wiring installations.

2. Possible postwar trend toward mass production of low-cost prefabricated homes which may require new methods of wiring.

3. The idea of introducing a so-called "ring-main" to supply the heavier appliance loads in the home.

4. Inclusion of convenience and safety in wiring design as well as sufficient capacity.

5. Consideration of an increase of minimum conductor size from number 14 to number 12 American wire gauge, a subject on which it was thought a comprehensive technical paper would prove helpful.

Discussions were solicited of a paper "Standards of Safety" which was read by S. B. Williams (M '37) at the conference session of the committee on domestic and commercial applications held during the 1943 AIEE winter technical meeting. A wiring session and conference at a future AIEE meeting was suggested, if sufficient papers could be obtained.

The report of the subcommittee on hazards to farm animals was presented by W. B. Buchanan (M '32) who discussed the conditions found on a number of detailed investigations of wiring installations on farms. A need was shown for further information in order to reach decisions regarding such matters as thorough grounding and the isolation of primary and secondary neutrals.

An opinion was expressed by Mr. Williams that the AIEE has been "ducking" the issue of safety, and that a subcommittee should be formed to investigate thoroughly the matter of hazards.

W. F. Ogden, chairman of the committee, presided, and M. K. Brody, secretary of the committee supplied the material from which this report was prepared.

Quality Control Discussed at St. Louis Conference

Control of the quality of products manufactured by the electrical industry by means of statistical methods was the subject of one of the technical conferences at the AIEE 1944 summer technical meeting in St. Louis, Mo. Various aspects of the subject were covered in five conference papers, three by manufacturers' representatives, one by a representative of the United Stated Ordnance Department, and one describing educational courses on the subject. A. S. Langsdorf (F '12), Washington University, St. Louis, presided.

Mass-production methods require that some means of quality control be applied, declared R. E. Wareham, General Electric Company, Schenectady, N. Y. He explained how statistical methods had first been applied to telephone work, referring to the early work of Shewhart and others; now statistical methods are being widely applied throughout the electrical industry. Mr. Wareham explained how better quality can be assured through better design and how statistical methods assist in achieving both the best machines and best methods of manufacture. He also described briefly the co-operative work in quality control now being conducted jointly by five engineering organizations and added that the AIEE had been invited to participate.

An intensive educational course in quality control was described by Paul R. Rider, Washington University, St. Louis. This course is being given in various industrial centers throughout the United States, the American War Standards being used as texts. He said that the course is being taken by men in a wide variety of industries.

Captain A. R. Burgess, United States Army, explained how statistical principles are applied by the Ordnance Department to check the quality of finished Ordnance matériel. Premature firing is one of the most important defects to be guarded against, he said, and inspection of selected samples based on statistical principles has proved more effective than 100 per cent inspection. Different types of inspection are applied to different products, and the size of sample is varied to meet specific requirements.

The application of statistics to the manufacture of dielectrics was described in a paper (44-113) by C. M. Summers (M '39) and K. E. Ross, General Electric Company, Fort Wayne, Ind., which was presented by Mr. Summers. The value of statistical methods in establishing a specification that adequately describes an insulation material was pointed out. The control chart method based on an agreeable sample size was suggested for determining whether or not the material adheres to the specification. "A virgin field is represented in the transformation of the characteristics of the material into data suitable for design purposes," stated Mr. Summers, who added that "the statistical method provides a powerful tool for analyzing such properties as the effect of time and temperature on the properties of material."

The savings and improvements that result by the application of sampling tests as compared with 100 per cent inspection of finished products were pointed out by Joseph Manuele of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., who described a specific application of the method to the inspection of plastic pulleys. When the manufacture of this item first was begun, there was 78 per cent scrap. Through the application of statistical methods, the defects resulting in this high proportion of scrap were discovered and remedied. Design tolerances were found to be satisfactory, but the dimensions of the mold were found to be at fault. Mr. Manuele said that statistical methods were being applied to both the tools and the methods of manufacture and that they are valuable for checking both materials and processes.

Temperature Standards Discussed in Two Conferences at St. Louis

Temperature standards for rotating machines in fractional- and integral-horsepower sizes were reviewed in two successive technical conferences (morning and afternoon) at the AIEE 1944 summer technical meeting held in St. Louis, Mo. These conferences represented a continuation of the activity begun at the 1944 winter technical meeting in New York. A series of conference papers was presented giving actual temperature-test results on various types and sizes of motors, by the following:

B. M. Cain (A'34) General Electric Company, Lynn, Mass.

L. H. Hirsch, Century Electric Company, St. Louis.

F. A. Himebrook (M'39) Master Electric Company, Dayton, Ohio.

T. C. Lloyd (A '31) Robbins and Meyers, Inc., Springfield, Ohio.

R. F. Munier (A '30) Emerson Electric Manufacturing Company, St. Louis.

F. D. Phillips (M '35) General Electric Company, Schenectady, N. Y.

M. L. Schmidt (M '41) General Electric Company, Fort Wayne, Ind.

C. P. Potter (F '39) Wagner Electric Corporation, St. Louis.

W. R. Hough (M '41) Reliance Electric and Engineering Company, Cleveland, Ohio.

The papers contained a large amount of data comparing temperature rise by thermometer, surface thermocouple, resistance, and embedded detectors, on open, totally enclosed nonventilated, and totally enclosed fan-cooled motors, with special emphasis on fractional-horsepower sizes. After presentation the papers were discussed at considerable length, and it was the consensus that in order to make this information available to the industry, the papers should be edited and published as a report of the committee on electrical machinery. A subcommittee, consisting of C. P. Potter, F. D. Phillips, and W. R. Hough has been appointed to do this editing. This committee hopes to make a permanent record of the figures that were submitted, in order that they may be available to all who may be interested, and particularly to the members of the AIEE committee on electrical machinery, the C-50 committee of the American Standards Association, and the general engineering committee of the motor and generator section of the National Electrical Manufacturers Association.

Presiding jointly at these conferences were F. E. Harrell (F '40) chairman of the AIEE committee on electrical machinery, and C. P. Potter (F '29) chairman of the subcommittee on induction machinery.

AIEE Board of Directors Met During Summer Meeting

The regular meeting of the AIEE board of directors was held at the Hotel Jefferson, St. Louis, Mo., June 29, 1944.

Proposed amendments to the AIEE constitution, recommended by the committee on constitution and bylaws, were approved for submission to the membership for vote early in 1945. The bylaws were revised as follows:

Section 67. Changed to read:

Sec. 67. The Board of Examiners shall consist of not less than twelve Fellows of the Institute. The duties of this Board shall be those defined in Section 44 of the Constitution.

Sections 30 and 31. Revised to read as follows:

Sec. 30. There shall be ten geographical Districts numbered and named as follows:

1. North Eastern	6. North Central
2. Middle Eastern	7. South West
3. New York City	8. Pacific
4. Southern	9. North West
5. Great Lakes	10. Canada

With the exception of certain deviations, resulting from the provisions of Section 31 of these bylaws, the territory covered by each of the ten geographical Districts shall be as shown on page 00.

Sec. 31. Wherever the territory of any Institute Section lies in more than one geographical District, as defined in Section 30 of these bylaws, the entire territory of said Section shall be included in the geographical District in which the headquarters of the Section are located.

The following territory was added to the South Bend Section: Starke and Pulaski Counties in Indiana (from the Chicago Section); Marshall and Fulton Counties in Indiana and Cass and St. Joseph Counties in Michigan (from the Fort Wayne Section); Van Buren County in Michigan (from the Michigan Section).

The committee on Student Branches was authorized to send certain selected literature to each Student when he enrolls in the Institute. Upon recommendation of that committee, the designation "Enrolled Student," was changed to "Student Member," and this action was referred to the committee on constitution and bylaws for the necessary revision of the bylaws.

The board approved in principle a recommendation of the committee on members-for-life fund that an appropriate first use of the fund would be the payment of the expenses to the summer convention (or technical meeting) of each of five authors of the papers winning the District Branch paper prize in the even-numbered Districts in the even years and the odd-numbered Districts in the odd years—each author to present his paper in person on the regular summer meeting program. These awards are to be announced only for the summer meetings of 1945 and 1946 and decision with respect to future years is to depend upon the reaction of the membership in general and the Student members in particular.

Upon recommendation of the committee on industrial power applications, the Standards committee, and the finance committee, the board appropriated $4,700 for the publication of 10,000 copies of a report on "Electric-Power Distribution for Industrial Plants," developed by the committee on industrial power applications, to be sold at 75 cents per copy to members and non-members alike, with a discount of 20 per cent on purchases of ten or more copies.

Decision was made to hold the 1945 summer technical meeting in Detroit, Mich., June 25–29.

The board adopted a resolution expressing to the members of the general committee and all subcommittees which arranged for the 1944 summer technical meeting its appreciation of the effectiveness of their planning and conduct of the various features which produced, despite wartime conditions, a well-balanced meeting receiving the enthusiastic approval of those present.

Other matters discussed were:

Minutes of the meeting of the board of directors held May 25, 1944, were approved.

Recommendations adopted by the board of examiners at its meetingon June 15, 1944, were approved, and the following actions were taken: 7 applicants were transferred to the grade of Fellow; 27 applicants were transferred and 41 were elected to the grade of Member; 194 were elected to the grade of Associate; 133 Students were enrolled.

Appropriation disbursements for June 1944 amounting to $26,711.44 were reported by the chairman of the finance committee and approved by the board.

Those present were:

President—Nevin E. Funk, Philadelphia, Pa. *Vice-Presidents*—L. A. Bingham, Boulder, Colo.; A. G. Dewars, Minneapolis, Minn.; W. J. Gilson, Toronto, Ont.; C. R. Jones, New York, N. Y.; E. T. Mahood, Kansas City, Mo.; K. B. McEachron, Pittsfield, Mass.; C. W. Ricker, New Orleans, La.; E. W. Schilling, Bozeman, Mont.; W. E. Wickenden, Cleveland, Ohio. *Directors*—T. F. Barton, New York, N. Y.; M. S. Coover, Ames, Iowa; K. L. Hansen, Milwaukee, Wis.; C. M. Laffoon, East Pittsburgh, Pa.; T. G. LeClair, Chicago, Ill.; F. R. Maxwell, Jr., Pensacola, Fla.; C. W. Mier, Dallas, Tex.; S. H. Mortensen, Milwaukee, Wis.; W. B. Morton, Philadelphia, Pa.; W. R. Smith, Newark, N. J.; R. G. Warner, New Haven, Conn. *National Secretary*—H. H. Henline, New York, N. Y. Also present by invitation were: *Past President*—A. M. MacCutcheon, Cleveland, Ohio. *Incoming officers*—G. A. Powel, East Pittsburgh, Pa.; R. T. Henry, Buffalo, N. Y.; R. W. Warner, Austin, Tex.; P. L. Alger, Schenectady, N. Y.; M. J. McHenry, Toronto, Ont.

The smooth functioning of the summer meeting reflected careful and painstaking advance planning by the summer meeting committee which was ably headed by B. D. Hull (F '39) Southwestern Bell Telephone Company, St. Louis, Mo. Here Mr. Hull was looking over the day's program

ABSTRACTS • • •

TECHNICAL PAPERS previewed in this section will be presented at the Los Angeles technical meeting, Los Angeles, Calif., August 29–September 1, 1944, and are expected to be ready for distribution in advance pamphlet form within the current month. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York 18, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at AIEE headquarters or at the meeting registration desk.

Air Transportation

44-180—Alternating Current Versus Direct Current for Aircraft Radio Power Supply; *D. E. Fritz (A '43), C. K. Hooper. 25 cents.* Aircraft radio power supplies generally have been selected to conform to the one type of power available on the airplane. New and larger aircraft are being developed which will have several types of power available for operating the radio equipment. In this paper a transmitter and a receiver have been analyzed to determine the weight, efficiency, reliability, and other important characteristics of the equipment. The fact that many voltages and frequencies are in use has influenced the authors to consider more than the basic subject of alternating current versus direct current and they have considered the power supplies in common use in addition to those being considered for use in the near future on new aircraft.

44-179—Electric Automatic Pilots for Aircraft; *P. Halpert (A '37), O. E. Esval (A '37). 20 cents.* The basic requirements of automatic pilots applied to airplanes are defined. Dynamic stability equations of the airplane are given in simplified form and the modified relations resulting from the superposition of automatic flight-control requirements are developed. The resulting equations establish some of the boundary conditions for the constants having to do with automatic pilot operation. An electric automatic pilot is described wherein functional control is obtained which substantially satisfies the equations. Various features of this automatic pilot, including automatic trim, automatic altitude control, and coordinated turn control are described. Performance characteristics are given and actual flight test data are included. The performance of this automatic pilot is shown compatible with theoretical requirements for the best suppression of attitude deviations of the airplane in any type of air turbulence.

44-181—The Gyrosyn Compass; *O. E. Esval (A '37). 15 cents.* The directional gyro, which has given such important service to flying, becomes more useful in the field of navigation when controlled by a method analogous to the erection of vertical gyros. An outline is given of the basic requirements for remote indicating compasses, which is a composite of demands from the Army and the Navy and other important groups. The general characteristics of the "Gyrosyn" compass, which was developed to meet these requirements is described. The importance of size, weight, and servicing considerations in obtaining stable magnetic-compass indications on airplanes subject to severe magnetic disturbances is demonstrated. The solution results in a compass system comprising a particular disposition of vital components. Extreme simplicity of those parts not convenient for servicing is adhered to rigidly.

44-182—Solenoid-Operated Hydraulic Valves for Aircraft; *G. A. Goepfrich. 15 cents.* A combination hydraulic and electric control system may have advantages over either type used alone, particularly in semi-automatic and automatic operations where considerable work must be done during a short period of time. This combination can be achieved by the use of solenoid-operated hydraulic valves. Solenoid-operated valves need not be installed at the control point but may be installed at any point that permits shortest possible hydraulic line length. Therefore, the total weight and vulnerability of the hydraulic system are reduced. Since solenoid-operated valves are electrically controlled, they lend themselves to semiautomatic and automatic operation. This feature is of particular importance in combat airplanes, since automatic operations will relieve the pilot of at least some mental and physical effort during combat. The development of pilot-operated poppet valves and hydraulic fluids with comparatively flat viscosity curves are two of the more important factors which made possible the reduction in weight of solenoid-operated valves to a degree practical for aircraft usage.

44-183—Electrically Heated Clothing; *G. H. Wetring. 25 cents.* As early as 1918 the need for heated clothing for aviators was recognized and several thousand fur suits

containing heating wires were produced. In 1940 the engineers of the General Electric Company who had developed the electrically heated blanket constructed their first electrically heated flying suit from plans worked out in collaboration with the Wright Field clothing unit. After much testing and many revisions, a design was adopted and production started in September 1941. This suit was the blue woolen undersuit frequently seen in photographs of flyers preparing for a bombing mission. Many improvements have been made in the electrically heated suit, shoes, and gloves during the war and electricity also has been used to heat oxygen masks and goggles. In fact, the use of electric heat to keep the flyers in fighting condition on the long cold flights to their targets is one of the principal applications of electricity on modern military aircraft.

44-184—Carbon-Pile Voltage Regulators for Aircraft; *W. G. Neild. 15 cents.* Increasing demands on the electric systems of modern aircraft and the corresponding enlarging of their electric power supplies have necessitated the use of high-field-current voltage regulators to effect appreciable weight savings. Carbon-pile voltage regulators are capable of controlling high field currents within close limits of regulation. They are rugged in construction and can be adapted to many different applications in both a-c and d-c systems. Absence of step or vibrating contacts greatly reduces radio interference and other faults peculiar to those types of regulators. The smooth resistance change offered by the carbon pile assures the steady regulated output voltage which is vital to many radio applications. Various wattage sizes are available and many different resistance ranges are made possible by the proper selection of the carbon pile. Carbon-pile regulators are of great interest to anyone having voltage-regulation problems.

44-186—D-C Arc Interruption for Aircraft; *J. S. Quill (A '43), L. T. Rader (M '43). 25 cents.* This paper presents data on d-c arc interruption for voltages up to 250 volts at pressures from sea level to 50,000-feet altitude. Both resistive and inductive loads are investigated. The load range chosen includes small currents corresponding to relay or auxiliary contact values and higher currents associated with power circuits. Two general types of devices were used for the tests: single- and double-break switches and a blowout-type contactor. The results are presented both in the form of maximum amperes which can be interrupted and arcing time in milliseconds. The effect of inductive loads on arc interruption are discussed briefly. Unexpected results were obtained for the higher d-c voltages, the data showing better interruption at altitudes greater than sea level. The blowout-type contactor is shown to be capable of interrupting large amounts of power at all altitudes if attention is paid to its low current limitation. There also are presented the results of an investigation on the effect of a magnetic field on an arc, which at increased altitude tends to produce an arc movement in a direction opposite to that at sea level. No attempt has been made to give theoretical or analytical explanations of the results obtained.

44-187—Electric Control in Automatic Pilots; *C. M. Young (A '38), E. E. Lynch, (M '35), E. R. Boynton. 20 cents.* Automatic pilots have been used satisfactorily to control aircraft attitude and course. They represent one step in the more complete problem of automatic flight control. Hence, their design and operation is of interest to those concerned with the more general flight-control problems. This introduction to automatic pilots defines the terms used in connection with them. It lists the qualifications for a satisfactory automatic pilot and states the purposes for which they are used. Understanding of their operation is simplified by describing first the fundamentals and then listing the equipment used to obtain this operation. The theory, from a qualitative point of view, is discussed with a simple mathematical analysis. A modern "relief" autopilot is described to illustrate specifically the decided advantages obtained by the recent conversion of some components to electrical operation.

44-188—Considerations in Servomechanism Design; *S. W. Herwald. 25 cents.* A servomechanism is, in general, any closed-cycle regulated system that is controlled by a difference of quantities. In this paper methods are outlined by means of which the steady-state and transient performance of servomechanism can be calculated. A general solution in operational form is given and specific solutions are derived for a number of different types of angular position servomechanisms. Among these is the solution for the Ward Leonard type of control with resistor-capacitor antihunt feedback. This is probably the most common type of angular position control.

44-189—Design of an Ignition System for an 18-Cylinder Aircraft Engine; *J. R. Harkness. 25 cents.* When initiating a new design, both the basic requirements and the desired advantages should be considered. The basic requirements for an aircraft ignition system are: sufficient voltage, at the proper time, over the full speed range, under all operating conditions and a system which fits the engine and airplane without interfering with any of the functions of the airplane. The desirable characteristics are: light weight and small bulk in a system easily installed and serviced, a minimum of maintenance, ease of manufacture by mass production methods, and a good physical appearance. These required and desired characteristics are discussed and some of the methods for obtaining them are presented. The concluding section of the paper is an elementary design analysis of the electric and magnetic circuits of an aircraft engine ignition system.

44-190—A 40-Kva 400-Cycle Aircraft Alternator; *H. E. Kreuipp (A '40), C. G. Veinott (M '34). 20 cents.* A-c auxiliary-power systems for aircraft date back to World War I. Recently, numerous technical articles have indicated an intense revival of interest in this subject. Heart of any electric system is the generator which supplies electric power to all parts of the system. An alternator, especially designed and built for 208-volt three-phase systems, is described in this paper. Light weight and reliability dominate the design, which involved a large number of new and unusual problems.

44-191—Inherent Overheating Protection of D-C Aircraft Motors; *C. G. Veinott (M '34). 20 cents.* Inherent overheating protection undoubtedly is one of the major developments in the fractional-horsepower-motor field in the last decade. Thermal protection now is advocated by some for aircraft motors and many thermally protected motors are now in aircraft service. In this paper are reported the results of a number of laboratory tests taken on a typical aircraft motor. Tests were taken on a 1/18-horsepower 7,500-rpm d-c motor. Loads ranged from locked-rotor to the minimum running load sufficient to trip the thermostat. Ambient temperatures ranged from −58 degrees centigrade to 78 degrees centigrade. Locked-rotor and running-overload temperature tests also were taken at a density altitude of 42,000 feet. Temperatures of the winding, frame, brushholders, and bearings were measured carefully under all conditions mentioned. Satisfactory protection without premature tripping invariably was achieved.

44-193—Influence of Electricity on Aircraft Instrumentation; *C. F. Savage (M '43). 15 cents.* The growth of the aviation industry during the present war has expanded the use of aircraft instruments and has set up conditions which have been very favorable to the electrification of aircraft instrumentation. The two factors which have been of primary influence have been the increase in size of aircraft and the wide range of operating conditions met by instruments. In order to indicate more clearly the expansion of electric instruments, two tabulations are included. One classifies aircraft instruments by functional use. The other tabulation identifies the operating principles of various kinds of aircraft instruments and subdivides them into their various classes. It is shown that many instruments are possible only because electrical principles are used in their design and it is shown also that certain few instruments which are relatively self-contained will continue to use only mechanical principles of operation. The necessity and advantages of electric systems for tachometers, gyroscopes, pressure instruments, automatic pilots, temperature indication, position indication, and compasses is discussed. The correlation between the individual measurements of a function and the adaptation to over-all systems is shown to be a major advantage of electric aircraft instruments. The adaptability of electric instrumentation to the most efficient power supply for the aircraft also is covered.

44-194—Aircraft Electrical Accessory Vibration Investigation; *D. R. Miller (A '42). 25 cents.* Flight measurements were made to determine the vibrations encountered by electric power-system accessories on four-engined bombardment aircraft. The flight tests were correlated with laboratory vibration tests to investigate design changes which were made to reduce failures of generator mountings and drive shafts and couplings. The paper presents flight vibration data and discusses investigations of causes of mechanical failures of generators. A general discussion of sources of vibration, accessory vibration response characteristics, and vibration test apparatus is presented. Recommendations are made for the mechanical design of accessories and their mountings.

44-195—Electric Gun Turrets for Aircraft; *J. D. Thompson* (*A '39*). *15 cents.* This paper briefly surveys the field of electric power drive equipment for aircraft gun turrets. Power drives are required for moving the guns against the high wind forces encountered in present-day aircraft slipstreams. They must be capable of fine control of speed and the speed must be smooth and constant under varying loads over a very wide range of speed and load. An overcompensated Amplidyne generator feeding a shunt motor is the system generally used. Speed is controlled by varying the Amplidyne excitation with a potentiometer; negative voltage feedback is used for stability. This gives a flexible system easily adapted to a variety of mechanical arrangements and auxiliary circuits which is being used successfully in large numbers in the present conflict.

44-196—Airline Aircraft Electrical-Equipment Maintenance; *W. A. Petrasek* (*A '36*). *20 cents.* The electrical maintenance problems of a typical commercial airline are reviewed and an outline of the required organization and procedure is presented. The design of electrical equipment for ease of maintenance is stressed and the importance of the electrical manufacturer's collaboration with the aircraft designer is emphasized.

44-197—Requirements for Aircraft Electric Motors; *E. R. Siefkin* (*A '43*). *15 cents.* Airplane designers constant insistence on reducing the weight of all parts of the airplane to an absolute minimum is having its effect on the design of aircraft electric motors. The slightly modified "general purpose" commercial motors of five years ago are rapidly being superseded by smaller, lighter, and more reliable motors designed for specific aircraft applications. In order that the optimum design may be achieved, the airplane manufacturer must furnish the motor designer with complete requirements for the specific application. The more important of these are described briefly with particular reference to 24-volt d-c motors.

44-198—Some Aspects of the Application of Induction Motors to Aircraft; *H. J. Braun* (*A '43*). *15 cents.* Fundamental characteristics of the three-phase induction motor are reviewed with respect to their possible application in aircraft. A brief review of present motor specifications is presented and test data are given on the operation of an induction motor with one or two lines shot away. Common types of motor loading are discussed with reference to the suitability of induction-motor drive for each. Curves are presented to illustrate the characteristics of motors and various types of loading.

44-199—Paralleling and Regulation of 24–28-Volt D-C Generators in Multi-engine Aircraft; *A. Siegal* (*A '42*), *D. DeCourcey* (*A '43*). *15 cents.* In this paper a revised electric bus system for aircraft is proposed which is intended to eliminate excessive variations in voltage and provide equal load division between generators and easier adjustment of component parts in service. Improved operational characteristics are obtained by regulating the voltages of the various generators at a common load center. These characteristics are obtained at no sacrifice of weight or vulnerability and without changes in the present equipment components.

44-200—Peak Voltages With D-C Arc Interruption for Aircraft; *V. E. Phillips* (*A '42*), *W. P. Mitchel* (*A '43*). *20 cents.* This paper presents experimental data on the high voltage peaks obtained with d-c interruption of an inductive circuit. Using a recently developed transient oscilloscope, peak voltages were measured on systems of 30, 60, 125, and 250 volts for simulated altitudes of from sea level to 50,000 feet. For the same voltage systems, peaks were measured for currents from 0.1 to 220 amperes, for double-break and single-break devices, and for loads ranging from pure resistance to very highly inductive. These loads included typical aircraft devices, such as motor fields and contactor coils, and the emphasis of this paper is on the application of the information to aircraft requirements.

44-201—Functional Design of Aircraft Electric Actuator Equipment; *C. E. Gagnier* (*A '43*). *15 cents.* The outline of this paper is included in its presentation to give a clear and concise picture of the factors that influence the design of an electric actuator for use on aircraft and to indicate the relative importance of the various factors. Chiefly interested in the design of this type of equipment are the electrical-engineering groups of the aircraft manufacturing companies, yet most of the problems involved are of a mechanical nature. For this reason, the paper mostly covers points of mechanical design on which the average trained electrical man is not fully informed. The length of the paper does not permit a complete solution of all design problems but does point out the existence of major problems and indicates the direction in which a rational design should proceed. This information will prove of value to the aircraft electrical engineer who must judge the work of the equipment manufacturer.

44-202—Circuit Protective Devices in Aircraft; *Walter Kenworth* (*Application pending*), *E. V. Sundt. 25 cents.* Some of the many fuses and circuit breakers used particularly in aircraft are described. Conclusions which show the reasons for the particular shapes of fuses, the time–current curves, temperature coefficients, resistances, ratings, testing, and manufacture are given.

44-203—A 120-Volt D-C Aircraft Electric System; *L. M. Cobb* (*A '34*). *25 cents.* This paper describes the 120-volt d-c system and the equipment used on the Navy flying boat Mars, the service requirements, and the problems incidental to development and design of the components of the system. Calculated weights for several arrangements of generating equipment including the installed system are tabulated for comparison and the weight of the installed 120-volt d-c system is compared with the weight of the 28.6-volt d-c system. A summary report on flight tests and service operations provides the basis for conclusions relative to the practicability of 120-volt d-c for large aircraft.

44-204—Basic Considerations in the Selection of Generators and Batteries for Aircraft; *L. M. Cobb* (*A '34*), *H. M. Winters* (*A '40*). *15 cents.* The flight safety of modern military and commercial aircraft is dependent on electrically operated instruments, communication equipment, flight controls, and other accessories to such extent that all factors affecting the selection of installed generator and battery capacities must be given weighed consideration during the design period to obtain maximum reliability of service. This paper describes a method of evaluating electrical loading of an airplane under applicable operating conditions and discusses the most important general factors which must be considered in conjunction with loading in order to provide adequate electric power supply for each condition of operation.

44-205—Problems in Applying Protectors to Electric Aircraft Motors; *L. W. Buell* (*M '44*). *25 cents.* The most important problems in applying protectors to aircraft electric motors are:

1. To locate and measure the danger hot-spot temperatures in the motor.
2. To establish the life expectancy of each of these hot spots at different temperatures.
3. To decide the minimum life expectancy of the motor for the application on which it is to be used.

After this information is known, it is a relatively easy matter to apply a protector to the particular motor. This paper attempts to answer these three problems. Also included are suggested methods of testing and examples of some of the unusual problems that have been encountered in the application of protectors to aircraft motors. No attempt is made to answer the question of whether or not protectors should be specified for particular applications. This paper pursues the subject of protection of aircraft electric motors only after it has been decided as necessary for a particular application.

44-206—The Development of Aircraft Position Lights; *Jack Vitol. 15 cents.* The need for a uniform system for the display and color of position lights on night-flying aircraft was demonstrated early in the history of aviation. Such a system was proposed at the Paris convention of 1919 and was adopted by many countries. Requirements of the Bureau of Air Commerce established as a result of the Air Commerce Act of 1926 stipulated the usage of lights which, in effect, conformed with this system. The need for additional light to give greater warning time for the faster aircraft in use by 1934 led to the requirement calling for a warning light. To meet this requirement, a 32-candlepower red lamp was used in at least one of the airplane's landing lights. With further increases in airplane speed and local congestion around airports, the results of a questionnaire indicated that the conspicuousness of aircraft had to be increased and such lights used as would be identifiable as belonging to an aircraft. Tests conducted resulted in using a two-color flashing light mounted on the tail of the aircraft and

flashing at a frequency of 40 cycles per minute. Supplementary top and bottom white fuselage lights were added and the flasher's circuit so wired that the red and green wing tip lights and the white taillight were on one circuit and the two white fuselage lights and the red taillight were on the other. This system of flashing lights has been in use now for almost two years and is being adopted either entirely or in part for use on certain military aircraft within the continental limits of the United States.

44-207—Magnetic Clutch for Aircraft Electric Motors; *Leo Andreiss, Fred Shanely. 15 cents.* Electric motors equipped with clutch-brake mechanisms have various important applications on aircraft. In this paper the purpose and operation of such a device is described and a thorough analysis of the magnetic circuit, as well as the forces involved, is presented. A comparison of a calculated and a tested magnetization curve is made to prove the validity of the calculations within reasonable limits. Braking efficiencies of high-speed intermittent-duty aircraft motors are illustrated. Motors incorporating these mechanisms have been used successfully on aircraft for at least the past three years. They are operated in a life test laboratory for a minimum of 10,000 cycles through the Air Corps duty cycle of three minutes on—seventeen minutes off as a preliminary acceptance test.

44-208—High-Altitude Brush Problem; *Dimiter Ramadanoff (M '37), S. W. Glass. 20 cents.* Rapid brush wear encountered on military aircraft at high altitudes is traced to low partial pressures of oxygen and water vapor. Brush wear, coefficient of friction, contact drop, and temperature have been studied on copper rings in vacuum chambers. Electrographitic brushes wear rapidly in dry oxygen at pressures less than 17 centimeters of mercury and in water vapor at pressures less than 19 millimeters of mercury at brush temperature of 135 degrees centigrade. Brushes wear rapidly in dried hydrogen, nitrogen, carbon dioxide, and neon atmospheres at pressures up to 76 centimeters of mercury. Through the use of vacuum chambers, brushes were developed that operate satisfactorily on copper rings in the presence or absence of oxygen and water vapor. These tests were confirmed on actual machines in altitude chambers simulating flight conditions as well as on actual plane tests at high altitudes. Compensation of electric machines and its effect on sparking and general brush performance is discussed.

44-209—A New High-Frequency Capacitor; *W. M. Allison, N. E. Beverly. 15 cents.* This improved high-frequency capacitor has a low impedance over a wide frequency range. That effects due to inherent inductance of the conventional two-terminal capacitor have been overcome by the operation of this improved capacitor as a transmission line is evidenced by the complete absence of resonant effects in the range studied. It is a three-terminal network used most efficiently in the same manner as the low-pass filter. In physical appearance and size the new capacitor is similar to conventional capacitors of the same low-frequency capacitance and voltage rating. These novel characteristics can be used advantageously over a wide frequency range to filter or by-pass radio-frequency noise from direct current or low-frequency current circuits, as circuit elements in conventional filters, and to by-pass multiband receivers and transmitters.

44-210—Design Considerations of 400-Cycle Aircraft Motors; *M. B. Sawyer, Sr. 15 cents.* The choice of high-frequency a-c power supplies for aircraft motors has necessitated consideration of new factors in the design of the motors which will be used. The requirements to be met by motors in aircraft applications are reviewed. The characteristics of 400-cycle motors are demonstrated by showing the effect of operating a standard 60-cycle motor on 400 cycles. The principal problems which were not present in the use of d-c motors are the low starting torque and the high breakdown torque of the 400-cycle motor. Various methods of improving the starting torque are discussed in the light of their effect on other characteristics of the motor and methods of handling high breakdown torque are suggested.

44-211—Very High-Frequency Radio-Noise Elimination; *T. B. Owen (A '43). 25 cents.* This paper shows that the methods of eliminating radio noise at medium and high frequencies apply equally at very high frequency. The aircraft-engine ignition system is analyzed to determine how it acts as a generator of radio-influence voltages, currents, and fields and each of the possible coupling paths between the ignition system and the radio receiver is examined. The method of radio-noise elimination by determining the coupling path to the radio receiver and controlling this path is discussed. The coupling paths into the receiver are examined and, finally, a radio-noise test program is outlined by which each path is isolated. Methods for controlling the various paths are suggested throughout the paper so that the proper radio-noise elimination methods may be used.

44-213—Radio-Noise Elimination in Military Aircraft; *G. Weinstein, H. H. Howell (A '43), G. P. Lowe (A '43), B. J. Winter (A '42). 15 cents.* This paper outlines a method of radio-noise elimination by which a great deal of preliminary radio design work can be accomplished prior to the completion of the prototype airplane. Methods of noise coupling to the receivers, effective shielding and filtering methods, and a proposed method for determining the maximum allowable conducted radio-noise level are discussed.

44-217—Brief Survey of Power-Supply Developments on British Aircraft; *P. W. Carter. 15 cents.* This paper traces briefly the development of power supplies on British aircraft from early wind-driven generators to the latest dual-purpose machines which provide both d-c and a-c. A description is given of the self-regulating d-c generator which was the main equipment of British airplanes during the period between the use of the early windmill-driven generator with Tirrill regulator and the fitting of the modern shunt machine with interpoles and other improvements and its carbon-pile regulator. Voltage regulators and the British technique of current limitation are discussed in some detail together with new trends in circuit design. In the field of alternating current a description is given of a typical engine-driven alternator and the necessity for dual-purpose machines for single-engine aircraft are touched upon together with a description of the British units available for this double duty.

44-218—Aircraft Electrical Horizons; *F. W. Godsey, Jr. (M '36), W. L. Berry (M '43), T. B. Holliday (M '43). 15 cents.* The advantages and deficiencies of electrical apparatus as used in aircraft are reviewed from the critical standpoints of both the designer and the user of such equipment. Particular emphasis is given to the presentation of electrical possibilities and prospects of the near future in aviation and specific objectives are outlined for the benefit of the electrical designer and the development engineer.

44-220—Solderless Terminals; *F. H. Wells, J. C. Balsbaugh (M '35). 20 cents.* In the last few years solderless terminals have found an increasingly wide application. The fields of application include aircraft, shipboard, communication, and general industrial work. One of the most important reasons for their increasing use is the substantially decreased labor required in their application compared with soldered terminals. The use of solderless terminals also gives assurance of a greater degree of uniformity with respect to both mechanical and electrical properties for the terminal conditions of the electric circuit. In general, the use of solderless terminals in both manufacture and application permits uniform machine production to replace the hand work necessary for soldered terminals. The paper discusses the following: description and method of crimping the solderless terminals, corrosion test procedures and electrical measurements, effect of a wide range of currents through the terminals and different temperatures, conductivity stability with different types of corrosion tests, different contact metals with copper and aluminum, and the effect of relatively heavy currents and elevated temperatures.

44-221—Historica Development of Electric Connectors; *E. J. Neifing. 15 cents.* This historical treatment of the development of connectors endeavors to survey briefly the various stages of electric-connector design and the expanding applications of the uses from the earliest types for heavy-duty power applications to the smaller and more intricate fittings in aircraft, electronics, sound equipment, television, and marine applications. Because of the broad scope of the subject, the material is treated in generalizations in order to cover the history within the space limitations of this paper. It is believed that connector design, materials, and manufacture are keeping pace with the requirements of new electrical equipment. Since the connector is essentially a component part of electrical equipment, its development is affected by the requirements of new electrical equipment, and through adaptations for the improvement of existing equipment is increasing operating efficiencies.

44-222—Electric Connections on Aircraft; *F. O. Stebbins (M '39), L. A. Taylor. 25 cents.* Poor electric connections easily can cancel the tremendous advantages of electric systems which perform vital functions on aircraft. Satisfactory connections are obtained by careful engineering, high-quality manufacturing, 100 per cent inspection, correct installation and proper servicing. Many factors and design details must be considered in the design of electric connections according to their service. Among the permanent connections, the soft-soldered type must be made without damage to the wire, insulation, or nearby electric contacts. Crimped types must be controlled accurately to obtain consistent quality. The stud and terminal semipermanent type similar to *NAS*-17 through 22 is one of the most reliable for severe service. Quick disconnect types sacrifice a degree of reliability for the quick disconnect features. The *AN* types need special design and inspection in order to give good service. A German design is protected from dust and water. The contact surfaces of the German connector can be inspected and cleaned easily. Sliding and operating connections require special design, materials, and testing to operate over the wide temperature, pressure, and humidity ranges experienced on aircraft.

44-223—Cable Used for Transmitting Electric Energy in Airplanes; *M. F. Peters, J. J. Phillips, Max Kronstein, H. B. Jealous. 30 cents.* A method is proposed for determining the current capacity and the temperature of operation of cables in airplanes. The cable selected in combination with the power plant should result in the smallest weight for each electric unit converted into useful work. A general equation is given for selecting the optimum current which is expressed in terms of the weight of the cable, power plant and fuel, the length and resistance of the circuit, and the operating voltage of the system. All bus bars and conduit should be enameled or painted to reduce their operating temperatures. The greatest reduction in weight of the electric system will be accomplished by increasing the voltage. If strip conductors are used, terminal connectors may be eliminated and the connecting of aluminum conductors simplified.

44-224—Requirements for Low-Voltage Aircraft Cable; *R. E. Hedges (A '44). 15 cents.* This paper presents the basic requirements to be expected of any electrical cable which is considered for use in aircraft. A few of the problems encountered in forming a cable specification are presented along with factors to be considered in establishing valid test procedures. The author has not attempted to give solutions to the problems presented but rather has attempted to acquaint the reader with the fact that a major problem does exist in designing an electrical cable suitable for use in aircraft. Many factors which are extremely variable must be considered before an adequate solution can be found.

44-228—Altitude Rating of Electric Apparatus; *Paul Lebenbaum, Jr. (A '37). 25 cents.* This paper studies the effect of altitude on the ratings of rotating electric machines and, after determining the fundamental principles involved, discusses these in relation to the application of such machines in modern aircraft. It is shown that the rating of a self-ventilated direct-engine-driven aircraft generator decreases rapidly with altitude and, at some altitude within the operating range of the plane, the generator may be able to dissipate only its no-load losses. It is also shown that an air-scoop ventilated direct-engine-driven aircraft generator maintains its rating over most of the operating range of present-day aircraft. Finally, certain sea level tests are proposed from which calculations of rating under altitude conditions can be made.

44-229—Plastics in Aircraft Electricity; *E. B. Cooper. 25 cents.* The principal physical properties of plastics commonly used as electrical insulation in aircraft are described and some of the limitations of each are pointed out. Properties of some of the new materials of potential use as insulation are given to the extent that secrecy orders permit. It is pointed out that tables of physical data on plastics usually lack several significant data and are therefore somewhat misleading. Data are given for repeated impact and for heat distortion under several loads to illustrate the need for more information than is given by the standard single-blow impact and single-load heat-distortion tests.

44-230—The Testing of Brushes for Life and Performance Under Various Altitude Conditions; *C. J. Herman. 20 cents.* This paper presents the author's experience in the testing of brushes on machines intended for high-altitude service on aircraft equipment. The procedure and range of conditions found useful in testing a wide variety of small a-c and d-c machines are outlined in detail. It is hoped that other investigators will contribute their experiences through discussions or additional papers and that from this material there may be developed a suitable test code supplementing the present Institute test code for d-c machines. The only real criterion of brush performance is that of actual experience in service, since the infinite variety of conditions that affect brush performance all cannot be anticipated under test conditions. However, carefully conducted tests over a range of specified conditions do provide a good basis for brush selection and greatly expedite the final choice for the best over-all performance. For this reason, and because it will be helpful to investigators in comparing their results, it is hoped that the proposed brush test code may be undertaken in the near future.

44-231—New Test Chambers for Aircraft Electric Apparatus; *E. R. Summers (A '38), J. F. Settle (A '42). 30 cents.* When electric machines were taken to high altitudes of 25,000 to 40,000 feet on modern military aircraft, the brushes wore rapidly, insulation sometimes failed, lubrication was uncertain, windings overheated, and other vexing problems appeared. New materials and methods were needed for this new environment. To accelerate the development of aircraft apparatus, air-conditioned chambers are provided to duplicate the cold clean dry rarefied air of the stratosphere. Facilities being used to test a range of equipment from totally enclosed one-watt computer motors to pressure-ventilated 40-kva alternators are described. Reasons are given for the selection of specific equipment. From simulated high-altitude tests under controlled conditions, designers are completing new apparatus more quickly, are predicting its performance better, and are reducing the amount of flight testing required to develop new aircraft.

44-233—Airplane Engine and Propeller Test-Cell Lighting; *D. H. Tuck. 25 cents.* There were many test cells constructed with very little thought given to lighting in the early rush of war preparations. The same mistakes that were made in the early cells were repeated in the new cells. This paper outlines these mistakes and means of correction. It gives details of a study of the fundamental principles of lighting as applied to test cells, a survey of existing test cells, and a method of applying lighting calculations to test-cell design.

44-234—Analysis of High-Frequency Ignition Circuits; *A. W. Robinson, Jr. (A '41). 20 cents.* Several types of high-frequency ignition systems for aircraft engines are now undergoing development. Most of them incorporate a Tesla-coil circuit, including a high-frequency oscillation transformer shock-excited by capacitor discharge. This paper gives a theoretical analysis of such a circuit with special emphasis on the effect of circuit constants on the efficiency of energy conversion. Neglecting losses, a theoretical efficiency of 100 per cent is reached when the primary and secondary circuits have equal natural frequencies and when the coefficient of coupling between circuits is 0.60. A graphical method is given to evaluate the effect on output voltage of a change in primary lead inductance. The effect of resistance losses also is discussed briefly for cases of practical interest.

44-237—Impedance of 400-Cycle Three-Phase Power Circuits on Large Aircraft and Its Application to Fault-Current Calculations; *C. K. Chappuis (A '41), L. M. Olmsted (M '39). 30 cents.* The theory of symmetrical components is reviewed as a method for determining fault currents in aircraft circuits. Positive and negative sequence impedance values are presented in convenient form applicable to circuit configurations now designed. The conventional formulae for line-to-line and three-phase faults are included to provide complete working information. Zero-sequence impedance has required extensive investigation. A series of tests in aircraft is analyzed to determine compliance with conventional power-system theory. An analytical solution has been employed to extend the test data to wire sizes and configurations of circuits now designed for large aircraft. Proximity to the ground return path in the aircraft structure proves to be an important factor in the zero-sequence impedance, the effect of which is shown by suitable curves. By combination of these components the zero-sequence impedance may be determined for use in line-to-ground fault calculations.

44-238—Higher-Voltage D-C Aircraft Electric Systems; *W. L. Berry, J. P. Dallas. 20 cents.* Many of the advantages of 115-volt d-c aircraft electric power are presented with frequent comparisons to 24-volt d-c and 208/-120-volt 400-cycle three-phase a-c power. System reliability is emphasized. Weight comparisons, favorable to 115-volt d-c power, are shown for power generation, distribution, and load components. Problems concerning the use of the two high-voltage systems are discussed and compared. The popular belief that 115-volt d-c switching and commutation is unsatisfactory at high altitudes is refuted. It is concluded that 115-volt d-c is the lightest and most practical of the proposed electric systems for both medium and large airplanes.

44-239—Applications of Electronics to Aircraft Flight Control; *W. H. Gille (A '37), R. J. Kutzler. 15 cents.* Even automatic flight control has been improved by electronics. In the type *C*-1 autopilot, developed by Minneapolis-Honeywell for precision flight control in bombing, six potentiometers measure electrically any deviation of the airplane's position with respect to gyroscopic references. The potentiometers are connected in three separate bridge circuits, one for each control axis, so that the signals produced for each axis are added algebraically. Each composite signal is impressed on an amplifier which operates a servo motor to adjust the airplane's control surfaces. A balancing potentiometer on each servomotor is connected in the bridge circuit to make the circuit self-balancing as the motor produces corrective control surface movement. Thus the control surface movement is proportional to the original signal as determined by the flight deviation. By means of the autopilot control panel, the human pilot can both execute maneuvers and make adjustments for variations in flight conditions.

44-241—Design Considerations for D-C Aircraft Generators; *J. D. Miner, Jr. (M '42). 20 cents.* Engine-mounted aircraft generators must fit within an envelope $6^1/_8$ inches in diameter by 14 inches long. Electric-power requirements on military airplanes are increasing so rapidly that the most urgent assignment confronting designers of aircraft generators is that of achieving the ultimate output possible from this envelope. In 1939 the maximum rating was 1,500 watts; in 1940, the maximum rating jumped to 3,000 watts; in 1942, to 6,000 watts. A rating of 9,000 watts is coming into use, and a rating of 12,000 watts is likely to be possible in 1944. A rating of 15,000 watts has been mentioned. New materials, new military demands, new design ingenuity, new manufacturing techniques, and new operating experiences all have had a part in introducing more advances in this field during the past four years than were made during the approximate 20 years of generator history prior to 1938. Methods by which these advances have been accomplished are described, and possibilities for future progress are indicated.

44-240—Instrumentation of 400-Cycle Aircraft Electric Systems; *A. J. Corson (M '43), A. G. Stimson, W. A. Soley (A '36). 20 cents.* New conditions, imposed by the rapid advancement of aviation, have affected the electric systems on aircraft. Recent trends have indicated that some future airplanes will use a-c power systems operating at frequencies of about 400 cycles. This paper treats the problem of instrumentation for 400-cycle aircraft power systems where it is desirable to measure active and reactive power, frequency, voltage, and current. Careful consideration of weight and space requirements is necessary in view of the fact that five quantities will be measured on a-c systems by the use of four indicating instruments, as compared with only two quantities in the case of the d-c system. A set of four $2^1/_4$-inch square instruments and the necessary current transformers and external resistors are described. The design of these instruments and accessories has been controlled so that their combined weight totals 2.6 pounds, which does not exceed the weight of the d-c voltmeter and ammeter (including the external 50-millivolt shunt), for use on systems of equivalent capacity. The design procedures are presented and performance data are tabulated on this group of compact aircraft instruments.

44-242—Solenoid-Operated Control Valves; *V. W. Eckel, O. H. Wiegarner. 15 cents.* The present trend towards larger multiengined aircraft has brought the question of various accessory power systems to the fore. This paper briefly summarizes some of the advantages of remotely controlled hydraulic circuits and suggests solenoid-operated valves as the most universally acceptable solution. Some of the problems involved in the design of solenoid valves are brought out and an acceptable design is described. Particular emphasis is given to the problem of matching the characteristics of the solenoid drive to that of the valve. The general conclusions are that:

1. The total installed weight of remote-controlled hydraulic systems is considerably lower than direct manually valved systems.

2. The simplicity and cost of the actual valve may have to be sacrificed to obtain the minimum installed weight.

3. Valves to be operated by solenoids should be designed for low operating forces and the solenoid force-travel curve should be made to match the valve curve to obtain the minimum total weight.

Industrial Power Applications

44-236—Vacuum-Tube Radio-Frequency Generator Characteristics and Application to Induction Heating; *T. P. Kinn (Application pending). 30 cents.* Induction heating by radio frequency rapidly is taking its place in many industrial processes. The high-power vacuum tube, in the past used only in radio applications, now is generating radio-frequency energy for industrial use. To apply this energy properly to industrial-heating problems it becomes necessary that engineers active in all phases of industry understand the characteristics and limitations of the vacuum-tube radio-frequency generator. The fundamentals of the vacuum-tube self-excited oscillator and design considerations which determine the characteristics of the radio-frequency generator are reviewed and illustrated. In general the characteristics show a high-impedance constant-current variable-voltage generator which requires manipulation of load circuits to load the generator properly. Methods are illustrated for accomplishing proper loading and numerical examples are given illustrating the formula and procedure necessary to any induction-heating problem.

Power Transmission and Distribution

44-185-ACO—The Influence of Mutual Coupling of Transmission Circuits on Ground-Current Distribution; *M. J. Lantz (A '43). 15 cents.* This paper discusses the causes and results of ground-current distributions that occur for a certain grouping of transmission circuits for single-phase-to-ground faults. These ground-current distributions result from the effects of mutual induction between intercoupled power-transmission circuits built in close proximity. Results discussed show that large unbalances of ground current in parallel circuits for faults external to them can occur from the influence of mutually coupled circuits. It is possible that the ground current flowing through a circuit to a more distant fault location can be considerably greater than the ground current flowing through the same circuit to a closer fault location. Large values of ground currents can be caused to circulate in a closed loop formed by parallel circuits which are coupled to another circuit carrying ground current. Ground currents can distribute unequally between similar parallel circuits which are affected unequally by mutual coupling.

44-215—An Analysis to Determine the Optimum Bussing Arrangements and Transmission Capabilities at Grand Coulee; *B. V. Hoard (M '36), G. W. Bills (A '38). 20 cents.* An unusual bussing arrangement at Grand Coulee generating station is described in this paper. It has been designated as the interleaved arrangement. The advantages offered by this plan include a reduction in circuit-breaker duty, an increase in system stability, and an increase in tran mission capability on lines that are heavily loaded. The plan further allows for maximum output of energy, which can be distributed in varying proportions to any one of three major load centers to compensate for diversity of local rainfall and hydroelectric generation. In solving the problem, the 230-kv bus was split but bus reactors were not used. Synchronizing power is obtained by interleaving lines from each load center to each bus. An increase in power in one load area is automatically available through decreases in other load areas without switching generators. Good operation also is obtained during emergency conditions with one line initially out of service, through use of spinning reserves and by arranging to drop a generator to prevent loss of stability.

44-226—New 138-Kv Underground Cable Lines in Los Angeles; *C. G. Mansfield (M '42). 30 cents.* The first 138-kv underground transmission cables to be installed west of Chicago and the largest now in use at this voltage (except for short station runs) were placed in service during 1943 by the Los Angeles Department of Water and Power. Although generally similar to 138-kv lines previously installed in the East, this installation involves a number of novel design features which make it of more than usual inter-

est. The paper describes these features and some of the studies of carrying capacity, cable movements, sheath voltages, oil supply and alarm, and sheath corrosion which led to their development and includes a summary of significant data and characteristics of the installation.

Protective Devices

44-192—230-Kv High-Speed-Reclosing Oil Circuit Breaker Tests; *A. C. Schwager* (*M '31*). *15 cents.* The advantages of high-speed reclosing of transmission lines in 20 cycles or less are well established for voltages up to 138 kv. Up to this date little experience is available however on reclosing 230-kv lines in 20 cycles or less, because breakers have not been available for such fast operation. This paper describes a 230-kv oil circuit breaker which is suitable for three-pole or single-pole reclosing with a reclosing time of less than 20 cycles. The performance of the breaker is established by field tests for high-speed-reclosing operation as well as for interruption of charging currents.

44-214—Field Determination of Current-Transformer Errors by the Secondary-Voltage Method; *E. C. Goodale* (*A'27*), *J. I. Holbeck* (*M '36*). *15 cents.* A test method is described in which progressively increasing voltages are applied to the secondary winding of a current transformer with its primary winding open-circuited. This allows an exciting current to flow. The 90-degree lagging component of this current magnetizes the core whereas the inphase component supplies the core losses. The paper describes a field method of analyzing the two components. In combination with the impressed voltage they are converted to susceptance and conductance. For a multiratio transformer, a turn ratio of 40 to one is usually chosen. Values of susceptance and conductance are plotted as ordinates on log-log paper with secondary induced voltage as abscissa. A family of diagonal lines are drawn to represent all turn ratios. For any turn ratio, values of susceptance and conductance are derived from these curve data. With the burden resistance and reactance known the phase angle and ratio errors may be determined by substitution in two simple formulas.

44-216—A New Distance-Type Relay With Adjustable Characteristics; *S. L. Goldsborough* (*M '43*). *15 cents.* This paper describes a new impedance distance-type relay with adjustable characteristics such that a partial or complete directional characteristic can be imparted to the impedance relay. This means that the impedance measurement in the direction of full load current and synchronizing surges from which the system can recover can be restricted very greatly without impairing the reach of the relay in the direction of fault ohms. A means is described for also varying the phase angle at which the directional characteristic is imparted to the impedance element. A discussion is given of a simple method of molding the relay characteristic to fit the short-circuit conditions of the line and load and synchronizing conditions of the system.

PERSONAL ● ● ● ●

L. M. Robertson (A '27, M '38) transmission and station engineer, Public Service Company of Colorado, Denver, has been awarded the 1943 District 6 prize for best paper for his paper, "Electric Performance and Investigations at High Altitudes." He was born January 20, 1900, and received the degrees of bachelor of science (1922) and electrical engineer (1927) from the University of Colorado and the degree of bachelor of laws from Westminister Law School in 1930. Mr. Robertson entered the employ of the Public Service Company as an electric meter tester in 1923 and was transferred to the electric distribution department. During 1923 and 1924 he gained experience in the accounting department, the results department, and with the line, station, and substation repair and construction crews. In 1924 he entered the transmission and station engineering department and in 1925 was placed in charge of the department. During 1937 he was an instructor in electrical engineering at the University of Denver.

A. E. Davison (A '13, M '44) transmission engineer, Hydro-Electric Power Commission of Ontario, Toronto, has been awarded the 1943 District 10 prize for best paper for his paper, "Meteorological Services for Designers and Operators of Electric-Power Systems." Mr. Davison, who was born in Grenville County, Ont., April 5, 1881, holds the degrees of bachelor of arts and sciences (1905) and civil engineer (1914) from the University of Toronto. From 1906 to 1909 he was assistant superintendent and engineering assistant for the Buffalo (N. Y.) Pole Line Construction Company. During the latter period he also practiced as a consulting engineer. In 1909 he joined the Hydro-Electric Power Commission of Ontario as design engineer and was later given supervision of all field work. Since 1915 he has been transmission engineer for the Commission. At one time he served as a Royal Commission of one to report on the building and operation of transmission and distribution systems in the Province of Manitoba.

J. W. Milnor (A '13, F '30) transmission engineer, Western Union Telegraph Company, New York, N. Y., has been named consulting engineer. Mr. Milnor entered the engineering department of the Western Union company in 1913 and from 1919 to 1936 was research engineer. In 1936 he was made transmission engineer. He had charge of the development of the system now employed in sending photographs by submarine cable from London to New York. He is the author of a number of technical papers and holds several patents. **F. B. Bramhall** (A '31, M '39) formerly engineer in charge of the transmission laboratory will succeed Mr. Milnor as transmission engineer, Mr. Bramhall joined the Western Union company in 1920 and held the positions of assistant engineer, engineer, and engineer in charge of research laboratory before his appointment as engineer in charge of the transmission laboratory in 1936.

J. G. Glassco (A '08, F '28) general manager, public utility department, The City of Winnipeg (Man.) Hydro-Electric system, will retire in September 1944. Born in Hamilton, Ont., September 10, 1879, Mr. Glassco holds the degrees of bachelor of science and master of science from McGill University. His career in the utility field commenced with employment with the Montreal (Que.) Light, Heat and Power Company in 1901. He was superintendent for the Southern California Edison Company, Ltd., from 1903 to 1905 and in the latter year became chief electrical engineer for the Dominion Power and Transmission Company. In 1909 he was made chief electrical engineer for the power construction department of Winnipeg and was appointed power engineer in 1911. He was made manager of the Winnipeg Hydro-Electric System in 1912.

W. R. MacDonald, Jr. (A'33, M '44) AIEE assistant editor on leave, has been released from active duty with the United States Army Signal Corps and has returned to the Institute's editorial staff. He was born August 22, 1910, in New York, N. Y., and received the degree of electrical engineer from Cornell University in 1932. He was originally employed on the AIEE editorial staff in April 1934. A first lieutenant in the Officers Reserve Corps, he was called into active duty in January 1941 and was assigned to the Office of the Chief Signal Officer in Washington, D. C., as head of the editing subsection, literature section, military training branch, where he was responsible for the preparation of field and technical manuals for the Signal Corps. He was successively promoted to the ranks of captain and major.

S. B. Farnham (A '36, M '42) engineer in the central-station engineering department, General Electric Company, Schenectady, N. Y., has been awarded the 1943 District 1 prize for best paper as coauthor of the paper, "A New Control System for Automatic Parallel Operation of Load-Ratio-Control Transformers." Born in New Haven, Conn., June 23, 1912, he holds the degrees of bachelor of science (1933) and electrical engineer (1935) from Yale University. He entered the testing department of the General Electric Company, Schenectady, in 1935 and was transferred to the switchgear engineering department in Philadelphia, Pa., in 1936. Since 1937 he has been employed in the central station engineering department at Schenectady.

H. C. Marcroft (A '31) test engineer, Pennsylvania Water and Power Company, Baltimore, Md., has been awarded the 1943 District 2 prize for initial paper for his paper, "Use of Dielectric Absorption Tests in Drying Out Large Generators." He was born March 30, 1902, in St. Paul, Minn., and was graduated from the University of Minnesota with the degree of bachelor of science in electrical engineering in 1924. He was employed as student engineer by the Commonwealth Edison Company, Chicago, Ill., until 1925 when he was placed in charge of the technical work of the system operating department of the Illinois Northern Utilities Company, Chicago. In 1929 he became

test engineer with the Pennsylvania Water and Power Company.

C. A. Laverty (A '33) electrical inspector, Boiler Inspection and Insurance Company of Canada, Montreal, Que., has been awarded the 1943 District 10 prize for initial paper for his paper, "Causes and Effects of Damage to Electrical Machinery and Switching Equipment." He was born in Limestone, N. B., January 9, 1903, and was graduated from the University of Alberta with the degree of bachelor of science in electrical engineering in 1928. After completing the students apprentice course of the Canadian Westinghouse Company, Montreal, he was transferred to the service department in 1930. In 1931 he joined the Boiler Inspection and Insurance Company as electrical inspector.

A. C. Marshall (A '14, F '29) president and general manager of the Detroit (Mich.) Edison Company, has retired. Mr. Marshall commenced his career as engineer for the Public Lighting Commission of Detroit from 1894 to 1899. He was chief engineer of the Rapid Railway System from 1899 to 1904 and became general manager of the Port Huron (Mich.) Light and Power Company in 1905. In 1912 he joined the Detroit Edison Company as assistant to the president and was appointed vice-president in 1913. In 1940 he was elected president. He has been general manager since 1923. Mr. Marshall holds directorships in several other companies.

Salvatore Minneci (A '38) electrical engineer, power transformer division, General Electric Company, Pittsfield, Mass., has been awarded the 1943 District 1 prize for best paper as coauthor of the paper, "A New Control System for Automatic Parallel Operation of Load-Ratio-Control Transformers." Born in Palermo, Italy, November 13, 1899, he received his technical education in the Mechanics Institute and the Bliss Electrical School. He entered the testing department of the General Electric Company in 1924 and since 1925 has been engaged in transformer engineering.

A. D. Hinckley (A '27, M '38) formerly assistant to the dean of the faculty of engineering, and instructor in electrical engineering, Columbia University, New York, N. Y., has been appointed executive secretary of the Illuminating Engineering Society, New York. Mr. Hinckley has been an instructor at Columbia University since 1934 and assistant to the dean since 1940. He has been director of the university's war training courses. At present a director and member of the council of the Illuminating Engineering Society, he also has served as its general secretary.

D. J. DeBoer (A '34, M '41) chief electrical engineer, Loup River Public Power District, Columbus, Nebr., has been appointed director of the Copper Wire Engineering Association, St. Louis, Mo. A 1922 graduate of South Dakota State College, Mr. DeBoer joined the central station engineering department of the General Electric Company, Schenectady, N. Y., in 1922 and Sargent and Lundy, Chicago, Ill., in 1925. Employed by the Harza Engineering Company, Columbus, in 1934, he became chief electrical engineer of the Public Power District in 1936.

H. R. Searing (A '20, F '30) formerly vice-president in charge of electric and gas operation, Consolidated Edison Company of New York (N. Y.) Inc., has been appointed executive vice-president. Mr. Searing has been employed by the Edison company since 1909 as tester, inspector, cadet engineer, assistant engineer, assistant superintendent, and assistant electrical engineer. In 1939 he became engineer of operation and in 1940 was promoted to vice-president. He is a director of the Brooklyn Edison Company and the Yonkers Electric Light and Power Company.

G. W. Swenson (A '19, F '36) professor and head of the department of electrical engineering, Michigan College of Mining and Technology, Houghton, has resumed his duties after an 18-month leave of absence to serve as civilian consultant and operational analyst with the Army Air Forces, Orlando Fla. He was recalled to replace **Chester Russell** (A '29, M '34) associate professor and acting head of the department who resigned to accept the position of electrical engineer with the Chandeysson Electric Company, St. Louis, Mo.

N. S. Hibshman (A '27, F '41) formerly head of the department of electrical engineering, New York University, New York, has been appointed director of the school of science and technology of Pratt Institute, Brooklyn, N. Y. A graduate of Pennsylvania State College, Professor Hibshman commenced his teaching career at Lehigh University, Bethlehem, Pa., where he served as assistant professor and associate professor. He was chosen head of the department of electrical engineering of New York University in 1942.

Edwin Fleischmann (A '22, M '29) formerly deputy chief of the fuel and allocation branch of the Office of War Utilities, Washington, D. C., has joined the research department of Gilbert Associates, Inc., New York, N. Y. Before resigning to head the emergency curtailment unit of the War Production Board in 1942, Mr. Fleischmann had been associated since 1927 with the Niagara Hudson Power Corporation system in Buffalo and Niagara Falls, N. Y.

J. F. Kotchevar (A '38) electrical engineer, Janetta Manufacturing Company, Chicago, Ill., has been named chief engineer of the company. Mr. Kotchevar was graduated from the University of Minnesota in 1928 and entered the employ of the Ideal Electric Manufacturing Company, Mansfield, Ohio, as design engineer. In 1935 he was meter engineer with the Northwestern Public Service Company, Huron, S. Dak., and in 1936 joined the Janetta company.

W. F. Westendorp (A '35, M '43) research engineer, research laboratory, General Electric Company, Schenectady, N. Y., has been awarded the John Price Wetherill Medal of the Franklin Institute "in consideration of his development of a successful high-voltage low-frequency resonance transformer of relatively small size and light weight, which is shockproof, efficient in operation, and particularly suitable for uses in high-voltage portable X-ray units."

J. N. Leedom (A '44) research radio engineer, Naval Research Laboratory, Washington, D. C., has been awarded the 1943 District 7 Branch paper prize for his paper, "Ultrahigh-Frequency Transmission in Hollow Guides." Born July 27, 1921, in Dallas, Tex., he was graduated from Rice Institute with the degree of bachelor of science in electrical engineering in 1943. Since his graduation he has been associated with the Naval Research Laboratory.

D. S. Young (A '28, M '36) formerly district engineer, Anaconda Wire and Cable Company, Chicago, Ill., has joined the Canadian Wire and Cable Company, Toronto, Ont. Before joining the Anaconda Company in 1928, Mr. Young was associated with the Electric Bond and Share Company, the Detroit (Mich.) Edison Company, and the Winnipeg (Man.) Hydro-Electric System.

F. B. Wright (A '08) formerly eastern zone distribution manager, Western Electric Company, New York, N. Y., has been appointed director of public relations. Mr. Wright has been employed continuously by the Western Electric Company since 1922. He has been manager of the company's distribution houses in Baltimore, Md., Washington, D. C., and Chicago, Ill. He was transferred to New York in 1928.

R. A. McCarty (A '16, M '32) vice-president of the Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa., has been granted a leave of absence to become special assistant to Maury Maverick, chairman and general manager of the Smaller War Plants Corporation, Washington, D. C. Mr. McCarty has been vice-president in charge of the Westinghouse company's subcontracting activities since 1941.

C. S. Lumley (A '23, M '29) formerly general manager, Roller-Smith Company, Bethlehem, Pa., has returned to the firm of Smith, Hinchman, and Grylls, Inc., Detroit, Mich., with which he was associated from 1926 to 1939 as industrial engineering manager. Mr. Lumley was district engineer for the Roller-Smith company in Chicago, Ill., and co-ordinating engineer and later general manager in Bethlehem.

W. N. Goodwin, Jr. (A '06, F '13) formerly chief engineer, and vice-president in charge of research, Weston Electrical Instrument Company, Newark, N. J., has been elected vice-president in charge of engineering. Mr. Goodwin, an employee of the company since 1898, has been chief engineer since 1906 and vice-president in charge of research since 1939.

R. H. Marsh (A '37) engineer, Southern California Edison Company, Ltd., Los Angeles, Calif., has been appointed chief engineer of the Machinery Manufacturing Company, Vernon, Calif. Mr. Marsh, who graduated from the California Institute of Technology, Pasadena, in 1936 entered the employ of the Southern California Edison company in 1937 as student engineer.

H. C. Rentschler (M '40) director of lamp research, Westinghouse Electric and Manufacturing Company, Bloomfield, N. J., recently received the Frank P. Bowen Medal from the Franklin Institute "in consideration of his application of a source of bactericidal ultra-violet radiation in air-conditioning systems in a scientific and practical manner."

H. J. Reeves (A '30, M '41) formerly chief of the engineering division of the Spokane (Wash.) Area Office of the United States Engineer Corps has resigned that position to accept the commission of lieutenant, junior grade, in the United States Naval Reserve. Before the war he was a consulting engineer in Spokane.

J. H. Harlow (M '43) formerly assistant superintendent of the economy division, Philadelphia (Pa.) Electric Company, has been appointed assistant mechanical engineer in the mechanical engineering division. A graduate of the University of Maryland, Mr. Harlow has been employed by the Philadelphia Electric Company since 1923.

J. M. Dollenmaier (A '40) formerly manager of the Detroit metropolitan and Michigan districts of the Line Material Company has been appointed assistant to the vice-president. Mr. Dollenmaier, a 1930 graduate of the Armour Institute of Technology, joined the Line Material Company in 1934 as sales engineer.

B. J. Wilkinson (A '33, M '34) formerly administrative assistant to the manager has been made district manager of the Niagara, Lockport, Ontario Power Company, Olean, N. Y. Mr. Wilkinson was sent to Olean as sales manager in 1931, became new business manager in 1938, and administrative assistant in 1941.

W. E. Goodwin (M '33) formerly of the air-conditioning department, Westinghouse Elevator Company, Jersey City, N. J., has been appointed negotiation manager. Mr. Goodwin has been with the Westinghouse companies since 1915, serving the companies in Europe, East Pittsburgh, Pa., and Springfield, Mass.

G. L. A. Thomson (A '15, M '24) electrical division chief, Public Service Electric and Gas Company, Newark, N. J., has been appointed assistant to the laboratory engineer. Mr. Thomson was employed in the testing laboratory in 1906 and has been chief of the electrical division since 1923.

R. J. Biele (A '36) formerly component parts engineer, General Electric Company, Bridgeport, Conn., has been appointed assistant engineer of the receiver division of the electronics department. Mr. Biele has been employed by the General Electric Company since 1935.

R. M. Gates (M '35) president of the Air Preheater Corporation, New York, N. Y., recently received the honorary degree of doctor of engineering from Purdue University and was cited "man of talent and of devotion to duty; acclaimed leader of the profession of engineering."

J. R. McFarlin (A '07, M '26) electrical engineer, Electrical Services Supplies Company, Philadelphia, Pa., has been elected secretary of the company. Mr. McFarlin has been associated with the company since 1907 when he was graduated from the University of Delaware.

L. H. Hardin (M '41) formerly senior electrical engineer, Tennessee Valley Authority, Wilson Dam, Ala., has resigned to become principal electrical engineer of the Santee-Cooper operations of the South Carolina Public Service Authority, Columbia.

T. R. Porter (A '38) formerly sales engineer, Westinghouse Electric and Manufacturing Company, Bloomfield, N. J., has joined the staff of the North American Philips Company, Inc., New York, N. Y., as technical-commercial expert on high-frequency heating.

L. B. Bender (A '20, M '27) retired colonel, United States Army, has been released from active military service and has resumed his position as engineer in the radio division, Westinghouse Electric and Manufacturing Company, Baltimore, Md.

B. H. McCoin (A '36, M '42) superintendent of the power bureau, Knoxville (Tenn.) Electric Power and Water Board, has been appointed field engineer in Atlanta, Ga., for the Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

Zay Jeffries (M '36, F '42) technical director, lamp department, General Electric Company, Cleveland, Ohio, has been elected to the board of trustees of Battelle Memorial Institute, Columbus, Ohio.

C. J. Lake (A '39) regulator engineer, induction voltage regulator department, General Electric Company, Pittsfield, Mass., has been transferred to the company's electronics division in Schenectady, N. Y.

C. W. Mier (A '25, F '39) engineer, Southwestern Bell Telephone Company, Dallas, Tex., has been elected first vice-president of the Texas Society of Professional Engineers.

F. R. Longley (A '25, M '42) electrical engineer, Western Massachusetts Companies, Springfield, has been elected vice-chairman of the electrical equipment committee of New England.

F. A. Hubbard (A '41) electrical engineer, New Bedford (Mass.) Gas and Edison Light Company, has been elected chairman of the electrical equipment committee of New England.

G. O. Mason (A '24, M '38) formerly electrical superintendent, Brown Shipbuilding Company, Inc., Houston, Tex., has been appointed assistant general superintendent for the company.

S. B. Williams (M '37) editor, *Electrical World*, New York, N. Y., has been elected president of the Illuminating Engineering Society.

E. C. Balch (A '22, F '43) chief engineer, Michigan Bell Telephone Company, Detroit, has been elected president of the Engineering Society of Detroit.

T. C. Clarke (A '35, M '42) district manager, Northern Electric Company, Vancouver, B. C., has been elected president of the Vancouver Board of Trade.

Wright Canfield (A '31, M '38) engineer, Public Service Company of Oklahoma, Tulsa, has been named director of the company's newly created research department.

F. R. McMeekin (M '40) formerly superintendent of transmission, South Carolina Electric and Gas Company, Columbia, has been appointed electrical engineer.

P. P. Kinnaman (A '22) formerly district operating superintendent, New Jersey Power and Light Company, Dover, has been made electrical engineer

OBITUARY • • • •

Joe H. Gill (A '12) chairman of the board and president, Electric Power and Light Corporation, New York, N. Y., and president of the United Gas Corporation died June 16, 1944. Born in Kerrville, Tex., September 25, 1886, Mr. Gill was graduated from the University of Texas with the degree of electrical engineer in 1910. After employment in the testing department of the General Electric Company, Schenectady, N. Y., from 1910 to 1912, he entered the employ of the Texas Power and Light Company, Dallas, for which he became general supervisor of design and construction of distribution and transmission systems. During World War I he served as first lieutenant in the United States Army. From 1919 to 1925 he was employed by the Dallas (Tex.) Power and Light Company first as salesman and later as assistant general manager of design, construction, and operation. He served as president and general manager of the Florida Power and Light Company, Miami, from 1925 to 1935 and as president of the Electric Power and Light Corporation since 1935.

A. H. Armstrong (A '98, M '04) retired engineer, died May 31, 1944. Born in Worcester, Mass., November 5, 1870, Mr. Armstrong was graduated from Worcester Polytechnic Institute in 1891 with the degree of bachelor of science in electrical engineering. Immediately entering the student course of the Thomson-Houston Electric Company at Lynn, Mass., he was transferred to Schenectady to work on a-c design in 1892 when the General Electric Company was organized. In 1894 he joined the engineering department and in 1897 the railway engineering department. Named consulting engineer of the transportation engineering department in 1929, he retired in 1930. He was a member of the National Electric Light Association, the American Railway Engineering Association, and the American Electric Railway Association.

Bichat Xavier Gremillion (M '41) division transmission engineer, Indiana Bell Telephone Company, Indianapolis, died May 28, 1944. Mr. Gremillion, who was born May 17, 1905, in Alexandria, La., received the degree of bachelor of science in electrical engineering from the University of Notre Dame in 1928. He entered the employ of the Indiana Bell Telephone Company as central office repairman, becoming student engineer in 1930. From 1933 to 1940 he was assistant engineer and in the latter year was made division transmission engineer.

Louis Teker (A '26) purchasing agent, Leeds and Northrup Company, Philadelphia, Pa., died June 11, 1944. Mr. Teker was born December 23, 1889, in Philadelphia and was graduated from Drexel Institute in 1912. Associated with Leeds and Northrup since 1909 he commenced employment as a draftsman and in 1916 was placed in charge of the purchasing department. He was a member of the American Society for Metals.

William Andrew Jackson (A '18, M '20) president, W. A. Jackson Company, Inc., Chicago, Ill., died June 1, 1944. He was born in Holden, Mo., August 6, 1872. After a period as general foreman of electrical construction for the Department of Electricity of the City of Chicago from 1896 to 1904, he formed the W. A. Jackson Company and served as its president until his death.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on July 20, 1944, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Adams, R. W., asst. district mgr., General Electric Co., Boston, Mass.

Fox, E. G., vice-president, Freyn Engg. Co., Chicago, Ill.

Knudsen, K. J., chief electronics engr., Lewis Engg. Co., Naugatuck, Conn.

Patterson, J. G., engr., New England Tel. & Tel. Co., Boston, Mass.

4 to grade of Fellow

To Grade of Member

Ashmore, O. B., Navy Dept. Bureau of Ships, Washington, D. C.

Beesley, R. J., asst. supt., Inland Steel Co., East Chicago, Ind.

Binford, H. F., associate elec. engr., N.A.C.A. Aircraft Engine Research Lab., Cleveland Airport, Cleveland, Ohio

Bohn, D. L., elec. engr., Aluminum Company of America, Pittsburgh, Pa.

Brown, A. W., asst. elec. distribution engr., Illinois Northern Utilities Co., Dixon, Ill.

Brown, M. J., design engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Brown, P. C., supt. of power, Whitehall Cement Mfg. Co., Cementon, Pa.

Caldwell, J. F., division engr., Georgia Power Co., Columbus, Ga.

Carlton, F. H., elec. engr., Sargent & Lundy, Chicago, Ill.

Conway, E. W., maintenance supt., Chesapeake & Potomac Tel. Co., Washington, D. C.

Cox, F. A., division engr., Public Service Comm. of Northern Ill., Maywood, Ill.

Crane, W. G., manpower co-ordinator, Bell Aircraft Corp., Marietta, Ga.

Duhamel, H. G., telephone engr., North Electric Mfg. Co., Galion, Ohio

Edwards, P. C., elec. engg., General Electric Co., Pittsfield, Mass.

Evans, Paul, design engr., Westinghouse Elec. & Mfg. Co., Sharon, Pa.

Hango, J. R., asst. mgr., Aluminum Company of Canada, Ltd., Montreal, Que., Can.

Harvey, G. C., asst. section engr., General Elec. Co., Fort Wayne, Ind.

Howe, P. J., asst. chief engr., Western Union Telegraph Co., New York

Kalbach, J. F., asst. design engr., General Electric Co., West Lynn, Mass.

Lee, H. R., chief of marketing and sales div., Bureau of Reclamation, Denver, Colo.

Lethert, C. W., elec. engr., Northern States Power Co., Minneapolis, Minn.

Levy, M. W., elec. engr., Kansas City Power & Light Co., Kansas City, Mo.

Logan, E. W., chief elec. engr., Emerson Electric Mfg. Co., St. Louis, Mo.

Long, L. W., sales engr., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Matheis, C. E., asst. engr., Allis-Chalmers Mfg. Co., West Allis, Wis.

Maxwell, J. P., switchgear engr., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Michaelis, J. L., elec. engr., Pittsburgh Plate Glass Co., New Martinsville, W. Va.

Miller, G. W., engr. in charge, Line Material Co., Zanesville, Ohio

Montgomery, D., elec. engr., International Minerals & Chemical Corp., Austin, Texas

Moser, M. X., plant protection engr., Wisconsin Telephone Co., Milwaukee, Wis.

Osborne, H. B., design engr., Ferranti Electric, Ltd., Toronto, Canada

Piccardo, J. E., research engr., Fairbanks, Morse & Co., San Francisco, Calif.

Ptuch, J. O., district elec. engg. officer, U. S. Coast Guard, Long Beach, Calif.

Poland, H. O., design engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Powell, C. S., contact engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Prideaux, C. F., project mgr., The Austin Co., San Diego, Calif.

Roessler, R. W., branch mgr., Westinghouse Elec. & Mfg. Co., Dallas, Texas

Ross, R. V., switchgear engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Seely, S., staff member, Mass. Inst. of Technology, Cambridge, Mass.

Sherwood, E. T., elec. engr., Globe-Union, Inc., Milwaukee, Wis.

Summers, E. R., induction motor engg. div., General Elec. Co., Schenectady, N. Y.

Thompson, J. K., mfg. engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Wetherby, T. C., elec. engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Wischmeyer, C. R., instructor in elec. engg., Rice Institute, Houston, Texas

Yeary, O. N., Fort Worth distribution supt., Texas Elec. Service Co., Fort Worth, Texas

Yeomans, I. L., associate engr., Signal Corps Ground Signal Agency, Ft. Monmouth, N. J.

46 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the national secretary before August 31, 1944, or October 31, 1944, if the applicant resides outside of the United States or Canada.

To Grade of Member

Allen, E. F., Manning, Maxwell, & Moore, Inc., Boston, Mass.

Carnes, T. L., Amer. Tel. & Tel. Co., Chicago, Ill.

Constable, J. M., Westinghouse Elec. & Mfg. Co., Baltimore, Md.

Cornell, C. L., Jr., N. C. Shipbldg. Co., Wilmington, N. C.

Donnell, F. L., Pier Equip. Mfg. Co., Benton Harbor, Mich.

Durling, C. R., Jr., Monitor Cont. Co., Baltimore, Md.

Erickson, G. L. (Reelection), Western Union Tel. Co., New York, N. Y.

Feldmann, W. H. (Reelection), Elec. Mach. Mfg. Co., Minneapolis, Minn.

Frostick, H. G., Westinghouse Elec. & Mfg. Co., Pittsburgh, Pa.

Germanowicz, S., Inst. de Elect., Montevideo, Urug., S. A.

Hardy, R. C. (Reelection), Gen. Elec. Co., Cleveland, Ohio

Houck, W. S., E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.

Johnson, R. W., Corning Glass Works, Corning, N. Y.

Jones, C. R., Carolina Tel. & Tel. Co., Tarboro, N. C.

Kaar, J. L., Gen. Elec. Co., Bridgeport, Conn.

Lazard, F., French Mission, Washington, D. C.

McBrayer, C. T., Signal Corps, U. S. Army, Dallas, Tex.

Peters, M. F., Titeflex, Inc., Newark, N. J.

Penn, H. L., Amer. Tel. & Tel. Co., Atlanta, Ga.

Picken, D. A., I.C.I. Ltd., Dowlais, Wales

Pitman, J. B., Sr. (Reelection), Alum. Co. of America, Torrance, Calif.

Radcliffe, A. E., Thomas A. Edison, Inc., Cleveland, Ohio

Reid, O. W., South African Airways, Germiston, South Africa.

Rich, A. (Reelection), Alfco Products Co., St. Louis, Mo.

Rushton, W. A. (Reelection), Bristol Aero. Co., Ltd., Hawthorn, England

Seibert, W. J. (Reelection), Gen. Elec. Co., Atlanta, Ga.

Shepherd, J. F., Sperry Gyroscope Co., Garden City, N. Y.

Smith, C. E., Taylor Winfield Corp., Warren, Ohio

Sweatt, T. O. (Reelection), Burns & Roe, Inc., New York, N. Y.

Tuck, D. H. (Reelection), Holophane Co., Inc., New York, N. Y.

VanMarter, G. L., Davis Transf. Co., Concord, N. H.

Van Sickle, E., Van Sickle Radio & Sup. Co., Indianapolis, Ind.

Youngstrom, C. H. (Reelection), Imperial Irrigation District, Imperial, Calif.

Zillger, W. H., Line Material Co., Philadelphia, Pa.

34 to grade of Member

To Grade of Associate

1. North Eastern

Bryson, R. W., U. S. Time Corp., Waterbury, Conn.

Cooke, E. F., Assoc. Factory Mut. Fire Ins. Co., Boston, Mass.

Palmer, G. A., New England Pr. Serv. Co., Boston, Mass.

Smith, C. H., Boston Edison Co., Boston, Mass.

2. Middle Eastern

Aufderhaar, A. D., Westinghouse Elec. & Mfg. Co., Lima, Ohio

Bacon, W. L., U. S. Navy, Washington, D. C.

Barnes, L., Radio Corp. of America, Camden, N. J.

Carpenter, P. M., Westinghouse Elec. & Mfg. Co., Pittsburgh, Pa.

Charlton, J. B., U. S. Navy Yard, Philadelphia, Pa.

Chevalier, J. H., National Elec. Coil Co., Columbus, Ohio

Dommin, L. A., American Ship Bldg. Co., Cleveland, Ohio

Gaugler, E. A., Naval Ord. Lab., Washington, D. C.

Harding, W. T., Major, Army Air Corps, Wright Field, Ohio

Jacobson, A. T. (Reelection), Allis-Chalmers Mfg. Co., Baltimore, Md.

Kenison, E. M., Federal Pr. Comm., Washington, D. C.

Reber, J. Gordon, Metropolitan Edison Co., Easton, Pa.

Wyatt, J. W., I-T-E Circuit Breaker Co., Philadelphia, Pa.

3. New York City

Brule, M. A., Gen. Elec. Co., New York, N. Y.

Cooper, E. B., E. I. du Pont de Nemours & Co., Arlington, N. J.

Lauinger, J. F., Jr., Conlan Elec. Corp., Brooklyn, N. Y.

Mujica-Quintanilla, L., Cia. Pervana de Telefonos, New York, N. Y.

Nittoli, A. J., U. S. Navy Yard, Brooklyn, N. Y.

Porter, H. R., Cent. Hudson Gas & Elec. Corp., Poughkeepsie, N. Y.

Swensk, A. L. (Reelection), Pub. Serv. Elec. & Gas Co., Newark, N. J.

West, W. B. (Reelection), U. S. Army, Fort Monmouth, N. J.

4. Southern

Graham, L. H., Major, U. S. Army, Robins Field, Ga.

Taylor, W. H., Elec. Storage Battery Co., Atlanta, Ga.

5. Great Lakes

Anderson, D. W., Northern Ind. Pub. Serv. Co., Hammond, Ind.

Blair, R. W., Gen. Motors Corp., Detroit, Mich.

Carroll, J. C., Jr., Hubbard & Co., Chicago, Ill.

Heinrich, K., Allen-Bradley Co., Milwaukee, Wis.

Hudson, W. J., Allen-Bradley Co., Milwaukee, Wis.

Lincoln, E. W., Fansteel Metallurgical Corp., North Chicago, Ill.

Lusher, M. H., Pub. Serv. Co. of Northern Ill., Chicago, Ill.

Lyons, C. E., Burroughs Adding Mach. Co., Detroit, Mich.

Meyer, J. C. (Reelection), Allen-Bradley Co., Milwaukee, Wis.

Peter, C. R., Allis-Chalmers Mfg. Co., West Allis, Wis.

Mahnke, E. C. (Reelection), 1400 E. 53rd St., Chicago, Ill.

Smale, V. E., Sparks-Withington Co., Jackson, Mich.

Whitton, A. W., Pub. Serv. Co. of Northern Ill., Evanston, Ill.

Williams, V. E., Dachel-Carter Shipbldg. Co., Benton Harbor, Mich.

6. North Central

Atkinson, R. G. (Reelection), Public Service Co. of Colo., Denver, Colo.

7. South West

Berwald, C. H., U. S. War Dept., Dallas, Texas

Collins, A. F., Moloney Elec. Co., St. Louis, Mo.

Phelps, G. O. (Reelection), Texas A. & M. College, College Station, Texas

Smith, G. A., Jr., Central Station Alarm Co., Dallas, Texas

8. Pacific

Berry, J. L., Westinghouse Elec. & Mfg. Co. Los Angeles, Calif.

Keehner, L. W., Moore Dry Dock Co., Oakland, Calif.

Ung, P. F., Hughes Aircraft, Culver City, Calif.

9. North West

Dickinson, H. K., Montana Pr. Co., Great Falls, Mont.

Drescher, R. D., Boeing Aircraft Co., Seattle, Wash.

Fernald, G. W., Puget Sound Navy Yard, Bremerton, Wash.

Hart, V. B., Boeing Aircraft Co., Seattle, Wash.

Hedin, E. R., Montana Pr. Co., Great Falls, Mont.

Hughes, P. R., Montana Pr. Co., Great Falls, Mont.

Karr, G. M., Montana Pr. Co., Great Falls, Mont.

Schubert, K. L., Boeing Aircraft Co., Seattle, Wash.

Shepparde, J. J., Jr., Boeing Aircraft Co., Seattle, Wash.

Suskin, H. H., Boeing Aircraft Co., Seattle, Wash.

Elsewhere

Bolus, J. E., Electricity Dept., Coventry, England

Campoy, H., Maquinaria y Materiales S. de R. L., Nogales, Mex.

Cotton, H. M., Radio Dev. Lab., Wellington, N. Z.

Johanson, H. A., Lago Oil & Transport Co., Aruba, N. W. I.

Total to grade of Associate

United States and Canada 59

Elsewhere 4

OF CURRENT INTEREST

SPEE Committee Reports on Postwar Engineering Education

The committee on engineering education after the war of the Society for the Promotion of Engineering Education has completed a report which was published in the *Journal of Engineering Education* for May 1944, and presented at the society's fifty-second annual convention, Cincinnati, Ohio, June 22–25, 1944. The committee operated under a directive to study the urgent problems of the immediate future as well as longer range problems of educational principle and practice, and particularly to review a 1940 report on aims and scope of engineering curricula in the light of future conditions as they can now be envisaged.

The 1940 report advocated the strengthening of engineering education by concentration on basic elements in the undergraduate years, organization of the curriculum in parallel integrated sequences of scientific-technological and humanistic-social subjects, and transfer of some of the more specialized subjects to the postgraduate period. The exigencies of war have tended to cause a reversal of the recommended process because special war training programs necessarily must be concentrated on the attainment of specific technical objectives. The committee now believes that with the cessation of hostilities the policy of expediency in engineering education should be abandoned and the evolutionary process of strengthening engineering education at its base resumed as quickly as possible.

In attacking its assignment the committee considered first matters of general policy, which are discussed in part I of the present report, and second, specific problems of the postwar period, which are discussed in part II. These specific problems include the adjustment of curricula to the needs of returning veterans, the adaptation of the college calendar to the postwar transition period, the possible effects of future universal military service, the rehabilitation of faculties, the restoration and strengthening of postgraduate study and research, and the study of lessons learned from war experiences that may be applied to the permanent benefit of engineering education.

Two general meetings were held by the committee, while other meetings were held by smaller groups preparing drafts of the report. These were reviewed by the entire committee, and a version circulated among a large group of educators both in and outside of engineering education.

Three major groups of students for whom plans should be laid are foreseen. These are:

1. Those who would follow engineering programs of the usual pattern, but with some modification.
2. Those preparing for careers in the operation and management of industry.
3. Those who would be fitted for unusual scientific and creative accomplishments.

Differentiation of curricula for the three groups would begin after the third year. Courses for the first two groups would require a total of four years, and for the third group five or more years.

The report suggests that changes may be necessary in order to meet criticism that there is waste in operating educational facilities less than a full calendar year, and foresees inevitable problems of financing higher education during a period of world-wide economic rehabilitation.

Members of the committee on engineering education after the war were H. P. Hammond, *chairman;* J. W. Barker (F '30), F. L. Bishop, E. S. Burdell, R. E. Doherty (F '39), N. W. Dougherty, H. T. Heald, F. G. Higbee, Sidney Kirkpatrick, C. E. MacQuigg, F. T. Mavis, E. L. Moreland (F '21), D. B. Prentice, H. S. Rogers, A. R. Stevenson (F '37), B. R. Teare (F '42), W. E. Wickenden (F '39) F. L. Wilkinson, B. M. Woods, W. R. Woolrich, and C. R. Young.

EDUCATION . . .

Veteran Program Augurs Postwar Boom for Colleges

American colleges and universities, which will be operating this fall at less than 40 per cent capacity, are facing the biggest educational boom in their history, according to an article in a recent issue of the *United States News.*

The tremendous enrollment increase expected will reflect two postwar conditions—an influx of returning veterans, honorably discharged from active military and naval service, who will continue their interrupted educational programs at Government expense, and the normal progression from high school to college of graduates no longer subject to drafting for selective service.

The first of these groups will be composed of all men and women who entered upon active duty in the Armed Forces after September 16, 1940, and before reaching the age of 25 who can claim any interference with their education because of service. Every veteran falling into this general classification who can meet the entrance requirements is entitled to a year's training in an approved college or technical school of his own choosing. The Government will pay up to $500 for his tuition and fees for the school year, and will give him a subsistence allowance from $50 to $75 a month. Longer service entitles him to as much as four years in college, studying straight through the calendar year, if he wishes, so as to get a full college course and two years of medicine, law, or graduate study in addition. There is no limit to the educational level, and the individual may engage in either full-time or part-time study.

The boom is not expected to manifest itself either immediately or suddenly, but the real influx will come, of course, with demobilization. The American Council on Education advises that from a possible million veterans returning to educational institutions, 250,000 to 400,000 probably will enroll on the college level. Because of the differences in their past training and the time lapse since their last period of study, the colleges are shaping courses and programs to fit the needs of four groups of students from the armed services. These groups are:

1. High-school graduates without college training.
2. Students who entered high school but did not finish.
3. College students.
4. College graduates.

The veteran in this first group of nearly 4,000,000, is as much as four years behind in his studies. However, with sufficient length of active service he may equip himself in two to four years to be a radio engineer, a businessman, a doctor, or a lawyer. Or in a year in the right college, he can train for a skilled mechanic's job or a position in business. Special tutoring and preparatory courses are being sponsored by many of the colleges for veterans in the nongraduate group. When this veteran is ready for college classes, he has the same choice as the graduate, or he may turn to a two-year course in a technical institute or junior college. A student from the group of 1,200,000 who started in college but did not finish may go on to graduation at his former college or a new one. Graduate doctors and lawyers will be allowed to take refresher courses or go on for further specialization, and older veterans with little or no college training can brush up on agriculture, business methods, or advertising.

One of the major problems the colleges are facing is how to adapt their programs to meet both the needs of veterans anxious of the speediest possible completion of their training and of the recent high-school graduates not accustomed to accelerated study.

INDUSTRY. . . . .

New Electrical Insulation Promises Higher Ratings

Insulating materials made from sand, brine, coal, and oil that have exceptional heat resistance offer major benefits to the electrical industry in the form of reduction of size and weight of equipment for a given output, increased life, or operation under conditions previously impossible.

The new materials are part of a series of substances, known as silicones, in the field of polymer chemistry lying between that of glass on the one hand and of organic plastics on the other which have been investigated by the Dow Corning Corporation, a new company formed by The Dow Chemical Company and the Corning Glass Works.

Future Meetings of Other Societies

American Association for the Advancement of Science. Annual meeting, September 11–16, 1944, Cleveland, Ohio.

American Chemical Society. 108th annual meeting, September 11–15, 1944, New York, N. Y.

American Society of Mechanical Engineers. Fall meeting, October 2–5, 1944, Cincinnati, Ohio; annual meeting, November 27–December 1, 1944, New York, N. Y.

Association of Iron and Steel Engineers. Annual meeting, September 25–27, 1944, Pittsburgh, Pa.

Edison Electric Institute. Accident prevention committee, September 12–13, 1944, New York, N. Y.

Electronic Parts and Equipment Industry Conference. October 19–21, 1944, Chicago, Ill.

Illuminating Engineering Society. Annual convention, September 14–16, 1944, Chicago, Ill.

Institute of the Aeronautical Sciences. Air transport meeting, September 1944, Washington, D. C.; fall meeting, November 1944, Dayton, Ohio.

National Electrical Manufacturers Association. October 23–27, 1944, New York, N. Y.

National Electronics Conference. October 5–7, 1944, Chicago, Ill.

National Industrial Chemical Conference and Third National Chemical Exposition. November 15–19, 1944, Chicago, Ill.

National Safety Congress of the National Safety Council. October 3–5, 1944, Chicago, Ill.

Society of Motion Picture Engineers. 56th semiannual fall conference, October 16–18, 1944, New York, N. Y.

Commercially available silicones include water-white fluids that remain at the temperature of dry ice as fluid as water, other fluids with the consistency of honey over a wide temperature range, varnishes and resins for use in electrical equipment where high-temperature operation is desired, and lubricating greases for uses involving high and low temperatures and chemical resistance.

Silicone materials for electrical insulation bridge the gap between conventional organic insulating materials and ceramic-type materials. Physically they are similar to conventional resins, varnishes, and organic structures, but they do not readily decompose at temperatures of the order of 200 degrees centigrade. In conjunction with glass-fiber and mica insulations, the new materials open many possibilities.

Electric Rates Reported by FPC. Typical electric bills for residential service in all communities of 2,500 population and more in the United States as of January 1, 1944, are shown in report FPC R-28, issued by the Federal Power Commission, Washington, D. C., and available at 25 cents per copy. The report includes typical net monthly bills for 15, 25, 40, 100, 250, and 500 kilowatt-hours of residential service in the communities covered.

Film for War Workers. "Brief for Invasion" is the title of a 33-minute motion-picture film produced by the War Department Bureau of Public Relations and available for exhibition to audiences of war-plant employees. Timed to coincide with present operations in Europe, the film is intended to show workers in war industries their role in invasion. Scenes from combat and captured German films are included, together with animated diagrams of German defense systems, to impress the need for an uninterrupted flow of matériel.

JOINT ACTIVITIES

Scientific Personnel Needed for New War Projects

The Office of Scientific Personnel of the National Research Council has been receiving a large number of requests for scientific and technical personnel from industrial and governmental laboratories interested in research personnel, from colleges interested in teachers, and from industrial establishments interested in a wide variety of scientifically trained persons.

Employers are most interested in candidates trained in physics, mathematics, geophysics, engineering (especially electronics, communications, electrical, mechanical, chemical), and neighboring fields.

The Office of Scientific Personnel, set up to serve in the war emergency, is in a position to refer an able scientist to employers engaged in urgent work. Therefore it is suggested that any persons who are, or who may be available for employment in the specified fields write to:

Dr. M. H. Trytten, Director
Office of Scientific Personnel
National Research Council
2101 Constitution Avenue
Washington 25, D. C.

AIEE Members Invited to Discuss ASCE Paper

Attention of AIEE members is called to the invitation from D. B. Steinman, consulting engineer, New York, N. Y., to participate in the written discussions of his paper, "The Rigidity and Aerodynamic Stability of Suspension Bridges," published in the November 1943 Proceedings of the American Society of Civil Engineers.

Mr. Steinman says: "The paper . . embraces phases of the problem in which engineers of other branches of the profession are interested and can make authoritative contributions. The bridge engineer needs the co-operation of experts in other fields, notably in the fields of vibration analysis and aerodynamics, if a complete solution is to be attained."

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Some Aspects of Inductance When Iron Is Present

To the Editor:

In the paper, "Some Aspects of Inductance When Iron Is Present," by L. T. Rader and E. C. Litscher (AIEE *Transactions*, volume 63, 1944, March section, pages 133–9) the authors state on page 135 that an accurate analytical expression for the saturation curve is quite unwieldy if it is desired to express B as a function of H. It also raises such questions as:

1. How can the relation between current and time best be found?

2. How can the stored energy and thence the inductance be found?

There exist various ways in which a saturation curve can be represented analytically such as algebraic or transcendental expressions and power, trigonometric, or other series. Considerable difficulty usually is encountered when any of these is substituted in differential equations and general solutions attempted. Still another way is to replace the actual curve by one consisting of two or more straight lines and to apply a linear solution to each part. Few solutions in which a power series has been used for the foregoing purposes have been published. A pair of such solutions follows.

In any given magnetic circuit, the relation between flux or flux density and ampere turns or current can be represented by

$$\phi = AB = a + bi + ci^2 + di^3, \text{ and so forth} \quad (1)$$

This includes saturation, hysteresis, magnetic leakage, and air gaps but not eddy currents which lead to more difficult mathematics involving Bessel functions. For many purposes two or three terms are sufficient.

Consider a 300-turn 0.09-ohm coil wound on a laminated core with an area of one

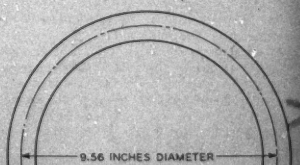


Figure 1

square inch and a mean circumference of 30 inches (Figure 1). From the saturation curve in Figure 2, we read for three points taken arbitrarily and obtain the statistics arranged in Table I.

Table I

Density	Ampere Turns Per Inch	Ampere Turns	Amperes
66,000	30	900	3
88,000	60	1,800	6
99,000	90	2,700	9

To determine the coefficients b, c, d, write equation 1 for each of these three points

$$\left.\begin{aligned} \phi = AB = 3b + 3^3c + 3^4d = 66{,}000 \\ 6b + 6^3c + 6^4d = 88{,}000 \\ 9b + 9^3c + 9^4d = 99{,}000 \end{aligned}\right\} \quad (2)$$

and solve simultaneously to give

$$\left.\begin{aligned} b &= 33{,}100 \\ c &= -4{,}280 \\ d &= 204 \end{aligned}\right\} \quad (3)$$

From this, the relation between flux and current

$$\left.\begin{aligned} \phi &= 33{,}100i - 4{,}280i^2 + 204i^3 \\ \text{and its time derivative,} \\ \frac{d\phi}{dt} &= (33{,}100 - 8{,}560i + 612i^2)\frac{di}{dt} \end{aligned}\right\} \quad (4)$$

When this coil is connected suddenly across a d-c electromotive force of $E = 0.993$ volt, the current must satisfy the equation

$$\frac{N}{10^8}\frac{d\phi}{dt} + ri = E \quad (5)$$

or, after substituting from equation 4 and transposing

$$\frac{di}{dt} = \frac{0.993 - 0.09i}{0.0993 - 0.0257i + 0.00184i^2} \quad (6)$$

Equation 6 can be integrated by one of the finite difference methods (those of Euler, Kutta, Runge, Adams, Piaggio, and others) or by transposing, dividing out, and integrating to find t in terms of i, from which

$$t = -0.0102i^2 + 0.06i - 0.441 \times \log_e (0.993 - 0.09i) + C \quad (7)$$

$t = 0$ when $i = 0$ so that the constant of integration $C = 0.441 \log 0.993$ and the final solution

$$t = -0.0102i^2 + 0.06i + 0.441 \log_e \frac{0.993}{0.993 - 0.09i}$$

$$= -0.0102i^2 + 0.06i + 1.015 \log_{10} \frac{1}{1 - 0.0906i} \quad (8)$$

From equation 8 we obtain the values in Table II.

Table II

i	t	i	t
0	0	9	0.469
2	0.167	10	0.593
4	0.275	10.5	0.844
6	0.339	11.03	
8	0.397		

When plotted this gives curve A, of Figure 3, similar in shape to that of Figure 13 in the paper. If a different number of terms had been used in equation 2, the work would have been similar. This is true also for the case of decreasing currents.

When the saturation curve is replaced by two straight lines as in Figure 2, the procedure is:

for lower part, inductance

$$L = \frac{\phi}{i}\frac{N}{10^8} = \frac{75{,}000}{3} \times \frac{300}{10^8} = 0.075 \text{ henry}$$

$$\text{current } i = \frac{E}{R}\left(1 - \epsilon^{-\frac{R}{L}t}\right) = \frac{0.993}{0.09} \times \left(1 - \epsilon^{-\frac{0.09}{0.075}t}\right) \text{ amperes}$$

at knee where

$$I = 3, \quad t = \frac{L}{R}\log_e\left(\frac{1}{1 - \frac{RI}{E}}\right) = \frac{0.075}{0.09} \times \log_e\left(\frac{1}{1 - \frac{0.09 \times 3}{0.993}}\right) = 0.265 \text{ second}$$

at intermediate point

$t = 0.13$ second; $i = 1.59$ amperes

for upper part, inductance

$$L = \frac{25{,}000}{9.5 - 3} \times \frac{300}{108} = 0.0115 \text{ henry}$$

current

$$i = \frac{E}{R} + \left(I - \frac{E}{R}\right)\epsilon^{-\frac{Rt'}{L}} = \frac{0.993}{0.09} + \left(3 - \frac{0.993}{0.09}\right)\epsilon^{-\frac{0.09}{0.0115}t'} \text{ amperes}$$

where t is counted from the knee ($t = 0.265$), from which we can deduce the data in Table III.

Table III

t	$t + 0.265$	i
0.135	0.40	8.22
0.3	0.565	10.26
0.7	0.965	11.0

Curve B of Figure 3 shows the plot for i from this basis. This completes the work for the relationship between current and time.

For question two, assuming first that the saturation curve has been replaced by two straight lines, the stored energy is, for lower part $i = 0$ to 3

$$\int_0^i L\frac{di}{dt}i\,dt = \int_0^I Lidi = \frac{LI^2}{2} = \frac{0.075 \times 3^2}{2} = 0.337$$

upper part

$i = 3$ to 9

$$\int_{i_1}^{i} L\frac{di}{dt}i\,dt = \int_I^i Lidi = \frac{L(i^2 - I^2)}{2} = \frac{0.0115 \times (9^2 - 3^2)}{2} = 0.415$$

a total of 0.752 watt-second.

These same results may be obtained also

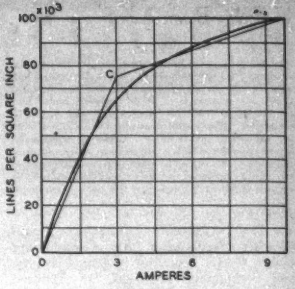


Figure 2

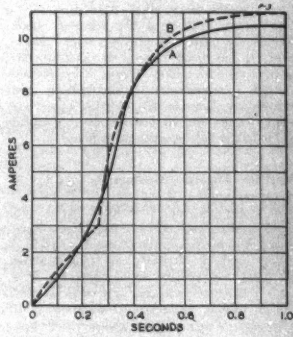


Figure 3

from the integrals of $eidt = \frac{N}{10^8}\frac{d\phi}{dt} \cdot i \cdot dt$, taken between the same pair of limits, when substituting

$$\frac{d\phi}{dt} = \frac{75{,}000}{3}\frac{di}{dt} \text{ and } \frac{25{,}000}{9.5 - 3}\frac{di}{dt}$$

respectively.

This total is lower than that obtained from the standard expression for constant μ, $\frac{B^2}{8\pi\mu}(cgs)$. At $i = 9$, $\mu = 345$, and stored energy = 1.35 watt-seconds. At $i = 3$, $\mu = 784$, and stored energy = 0.338 watt-second.

For comparison when using the power series, for $i = 9$ amperes, the stored energy is

$$\int_0^i eidt = \int_0^t \frac{N}{10^8}\frac{d\phi}{dt} \cdot i \cdot dt = \int_0^t \frac{300}{10^8} \times (33{,}100 - 85{,}60i + 612i^2) \cdot i \cdot di$$

$$= 0.0496i^2 - 0.00856i^3 + 0.000459i^4$$

$$= 4.02 - 6.24 + 3.01 = 0.790 \text{ watt-second}$$

and the inductance, $L = \frac{2 \times 0.790}{9^2} = 0.0195$ henry.

It thus appears that cases exist for which the power series is a competitive tool and that its application merits further investigation. Several recent books indicate that such work is in progress.

A. F. PUCHSTEIN (M'27)

(Electrical engineer, the Jeffrey Manufacturing Company, Columbus, Ohio)

NEW BOOKS • • •

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Heating, Ventilating, Air Conditioning Guide 1944. American Society of Heating and Ventilating Engineers, 51 Madison Avenue, New York, N. Y. 1,168 pages; roll of membership 104 pages, illustrated, 9 by 6 inches, fabrikoid, $5. (ESL.)

The new edition of this reference book follows the pattern of previous ones. However, it has been revised thoroughly and many new data added to bring it up to date. A new chapter on marine heating and ventilation has been added. The new edition maintains its position as a practical guide to the best practice in its field.

Aircraft Analytic Geometry. By J. J. Apalategui and L. J. Adams. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1944. 285 pages, illustrated, 8½ by 5½ inches, linen, $3. (ESL.)

The methods of plane and solid analytic geometry are applied to the solution of a certain class of problems that arise in the design, lofting, tooling, and engineering of airplanes. There is also a treatment of conic sections as used in design and lofting. The approach is systematic and is based on the principles of plane and solid analytic geometry.

Basic Mathematics for Engineers. By P. G. Andres, H. J. Miser, and H. Reingold. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1944. 726 pages, illustrated, 8½ by 5½ inches, cloth, $4. (ESL.)

This book presents in one volume "the mathematics required for an intelligent pursuit of elementary engineering courses and serves as preparation for a course in the calculus." It contains those topics from algebra, trigonometry, and analytic geometry needed to meet these objectives. The text is suitable for home study by students who have had two years of high school mathematics.

Calculus Refresher for Technical Men. By A. A. Klaf. McGraw-Hill Book Company, Inc., Whittlesey House division, New York, N. Y., 1944. 431 pages, illustrated, 8½ by 5 inches, cloth, $3. (ESL.)

The basic concepts and methods of differential and integral calculus are presented in question and answer form in this book, which is intended especially for men who have studied the subject and wish to review it rapidly. Typical examples are worked out and problems are provided for the student. A section is devoted to practical applications of calculus to engineering.

Control of Electric Motors. By P. B. Harwood. Second edition. John Wiley and Sons, Inc., New York, N. Y.; Chapman and Hall, London, England, 1944. 479 pages, illustrated, 8¾ by 5½ inches, cloth, $5. (ESL.)

In this book the characteristics of various types of motors are described briefly and the way in which these characteristics are used to control them are explained. The design, construction, and operating characteristics of a number of controllers and control devices are discussed and methods of combining these devices to secure a desired effect are described. New material has been added in this edition on variable-voltage control and synchronous motor control, electronic control, and so forth.

Electrical Technology and the Public Interest. By F. J. Kottke. American Council on Public Affairs, Washington, D. C., 1944. 199 pages, tables, 9 by 6 inches, paper, $2.50; cloth, $3. (ESL.)

This study of our national policy toward the development and application of inventions discusses the extent to which leading concerns can or do control the electrical industry through ownership of patents on the most effective technological methods. The effects of the patent privilege, the part played by company research laboratories, and the matter of patent licensing are discussed at some length. The recommendations of the Temporary National Economic Committee are discussed.

Foundations of Potential Theory. By O. D. Kellogg. Published by the Murray Printing Company; distributed by Frederick Ungar Publishing Company, New York, N. Y., 1944 reprint, 384 pages, illustrated, 9½ by 6 inches, linen, $6. (ESL.)

This is a reprint of the treatise by the late Professor Kellogg which was published in Berlin in 1929 and which was based on his courses at Harvard University. The first quarter of the book treats the subject in a fairly elementary manner, with applications to gravitational theory, electrostatics, magnetostatics, and the flow of heat but the remainder is more mathematical. The restrictions on the validity of the equations of Gauss and Stokes are examined, and the Dirichlet problem investigated.

Internal Combustion Engines. By B. H. Jennings and E. F. Obert. International Textbook Company, Scranton, Pa., 1944. 471 pages, illustrated, 9 by 6 inches, cloth, $4.50. (ESL.)

This text is designed to give students and engineers fundamental and factual knowledge of the broad field of internal combustion engines. Basic analyses are developed in detail for the many processes in the engine and illustrative applications are drawn from current technical literature and manufacturing practice.

Introduction to Electric Power Systems. By J. G. Tarboux. International Textbook Company, Scranton, Pa., 1944. 385 pages, illustrated, 8½ by 5¼ inches, fabrikoid, $4.50. (ESL.)

Two general fields are covered in this textbook, the theory and operation of power-transmission systems under balanced steady-state conditions and system characteristics under unbalanced or faulty operation. The introductory material on inductance and capacity is brief, as the student is assumed to be well grounded in these fundamentals. The object of the book is to prepare the student particularly for work in the operating departments.

Magnesium. By E. V. Pannell. Pitman Publishing Corporation, New York, N. Y., and Chicago, Ill., 1944. 137 pages, illustrated, 9 by 5½ inches, cloth, $4. (ESL.)

In this practical treatise on magnesium from the engineering and industrial point of view, the methods of producing the metal are described briefly. Most of the book is devoted to the alloys, their heat treatment, casting and working, corrosion and protective methods, and their industrial application. The book is a useful addition to the literature on magnesium.

Military Maps and Air Photographs. By A. K. Lobeck and W. J. Tellington, with an introduction by J. K. Wright. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1944. 256 pages, illustrated, 11½ by 8½ inches, cloth, $3.50. (ESL.)

The authors, a geologist, and an army topographer, have aimed to supply a complete, yet simple, presentation of the fundamentals of map reading and map interpretation, including air photographs. Techniques and methods are described in detail. Especial attention is paid to the representation of topographic forms by contours though a section is devoted to landscape types. Engineering students, as well as military men, will find the book useful.

Mr. Tompkins Explores the Atom. By G. Gamow. The Macmillan Company, New York, N. Y.; the University Press, Cambridge, England, 1944. 97 pages, illustrated, 8½ by 6½ inches, cloth, $2. (ESL.)

In this admirable bit of scientific humor, Professor Gamow pursues the further adventures of the hero of "Mr. Tompkins in Wonderland." His attendance at a series of lectures on nuclear physics results in three strange dreams for Mr. Tompkins in which he learns of Maxwell's Demon, adventures among the electrons with disastrous results, and probes the mysteries of the nucleus.

Questions and Answers for Marine Engineers. Compiled by H. C. Dinger. *Marine Engineering and Shipping Review*, New York, N. Y., 1944. 330 pages, illustrated, 8½ by 5 inches, paper, $2. (ESL.)

This book gives practical answers to problems that confront marine engineers. The operation and maintenance of pumps, condensers, and other auxiliary machinery; the application of steam and heat in producing power, and powering; propulsion; propellers; and shafting are the subjects covered.

PAMPHLETS • • • •

Guide to Postwar Financial Planning for Manufacturers. National Association of Manufacturers, 14 West 49th Street, New York 20, N. Y., 18 pages.

Air Express Now and Tomorrow. By L. O. Head. Railway Express Agency, 11 pages.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Gas-Filled-Cable Research and Experience

G. B. SHANKLIN
MEMBER AIEE

RESEARCH and engineering studies of gas-filled cable were started about 12 years ago by the company with which the writer is associated and this development work has been carried on continuously since then. Useful results in the form of practical cable designs have resulted and more will follow in the future as our knowledge of the basic principles of this type of cable increases. The present paper will be in the form of a progress report summarizing results obtained since the first two papers[1,2] on this subject were presented before the AIEE in 1939 and 1942. The same methods of test and analysis of test data described in the previous papers will be followed and, although an attempt will be made to have the present paper complete in itself, it will be necessary to refer to the older papers frequently to avoid repetition.

The soundness of gas-filled-cable design is now well proved by more than five years of practical operating experience and this type of cable can no longer be considered experimental. There have been no service failures or signs of insulation deterioration and during this period a total of something like 20 separate installations involving low-, medium-, and high-pressure types, at voltage ratings from 15 to 120 kv, have been produced in this country by cable manufacturers. Most of this experience has been with the low-pressure type at voltage ratings up to 38 kv. There has, however, been limited experience with the medium- and high-pressure types. Uniformity and control of dielectric characteristics through gas-pressure control, simplicity of design and operation, economy, self-supervision of mechanical defects, and other features assure future usefulness.

Paper 44-133, recommended by the AIEE committee on power transmission and distribution for presentation at the AIEE summer technical meeting, St. Louis, Mo., June 26–30, 1944. Manuscript submitted March 27, 1944; made available for printing May 12, 1944.

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The author acknowledges the co-operation of J. B. Felter, who carried out the laboratory tests, V. A. Sheals, L. Wetherill, C. A. Piercy, L. L. Phillips, and A. R. Lee.

Ionization as a Function of Gas Pressure

The establishment of a reliable curve showing initial ionization starting voltage as a function of gas pressure furnishes a useful and important guide for design and operation of gas-filled cable. A curve of this kind was given in the last paper[2] and its significance was discussed at some length. Due to the ionization self-extinguishing effect in mass-impregnated gas-filled cable, which will later be dealt with in detail, the initial ionization starting voltage represents an operating voltage limit that can be closely approached with safety. In this respect, gas-filled cable is the only known type that offers a direct way of predetermining safe operating voltage stress and insulation thickness by means of a simple, short laboratory test on advance samples. It is for these reasons that close attention has been paid to the establishment of a reliable average curve of this type.

The curve in the earlier paper[2] was known to be accurate up to a gas pressure of 30 pounds per square inch, since it was based on a number of separate tests up to that pressure. Additional tests made during the past two years have confirmed this. There were reasons, however, to doubt the old curve at pressures above 30 pounds per square inch. For one thing, the shape of the curve at the higher pressures did not agree with theoretical calculations, having too much droop. The peculiar shape of the power factor curves in Figures 3 and 4 of the first paper[1] also indicated the possibility of extraneous effects. Later, it was confirmed that the gas-filled test terminals were faulty and terminal discharges accounted for these discrepancies. Additional high-pressure measurements have since been made under better controlled conditions.

Figure 1 gives power-factor curves at pressures from 15 to 55 pounds per square inch on a commercial length of 46-kv three-conductor gas-filled cable with double-reinforced sheath. The cable was impregnated with standard number 5317 compound and had received the usual standard treatment and compound drainage before test. It will be noted that ionization voltage up to 30 pounds per square inch agrees with that measured on standard low-pressure gas-filled cable as reported in the past[1,2] the ionization voltage stress being 85 volts per mil at 15 pounds per square inch.

Figure 2 shows corresponding power-factor curves at pressures from 10 to 225 pounds per square inch on a special length of hollow-core single-conductor high-pressure cable in a steel pipe. It

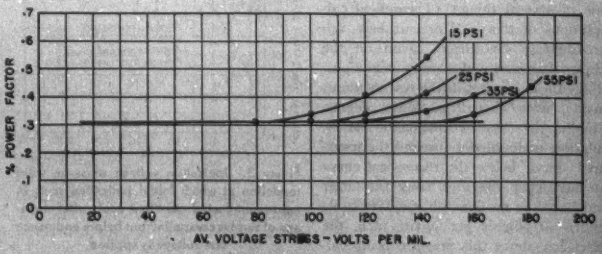

Figure 1. Three-conductor medium-pressure gas-filled cable, 400,000 circular mils, compact round conductors, strand shielding, 0.280-inch insulation, rated 46 kv to operate at 40-pounds-per-square-inch nitrogen pressure, showing initial ionization starting voltage at different pressures after drainage of surplus compound before load-cycle aging test

Measurements at room temperature

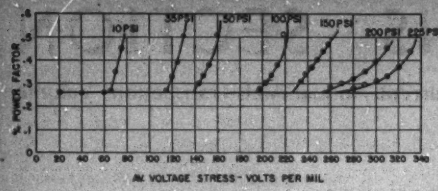

Figure 2. Single-conductor high-pressure gas-filled cable—350,000-circular-mil conductor with one-half-inch hollow core, strand shielding, 0.300-inch insulation, lead sheath, cable in steel pipe, showing initial ionization starting voltage at different pressures after very severe drainage of insulation at 100 degrees centigrade

Measurements made at room temperature

was also impregnated with standard number 5317 compound in the usual way but the compound drainage treatment was much more severe than standard, the purpose being to remove all possible surplus compound from the insulation and thereby obtain more sharply defined curves. It is always difficult to obtain sharply defined ionization starting voltage with standard cable, especially at the higher pressures. Obviously, also, such results obtained on severely drained cable are on the safe side when applied to standard cable.

In this case, drainage treatment before leading consisted of application of ten pounds per square inch nitrogen pressure to the conductor core, with the reel length under vacuum in an impregnating tank at 100 degrees centigrade. This forced drainage continued for two days and examination of end samples showed the whole cable cross section to be quite "dry," with little evidence of surplus compound between tapes. This "dry" condition is further verified by the sharply defined ionization curves in Figure 2, and the relatively low ionization starting point of 65 volts per mil at ten pounds per square inch. Standard cable averages 75 volts per mil at this pressure.

The results in Figures 1 and 2 were replotted in Figure 3 and a revised curve of initial ionization starting voltage as a function of gas pressure constructed as shown. Up to 30 pounds per square inch this curve is the same as the old one.[2] Above 30 pounds per square inch the new curve has a much more rational shape and agrees better with the theoretically calculated curve. That there is not closer agreement might be due to any one of several things. Theoretical calculations of this kind are, at best, approximate. Extraneous results at the higher pressures and stresses might possibly still be present in the test measurements, even though of lesser degree. Finally, the "dry" condition of the insulation undoubtedly lowered the measured curve below the theoretical curve at the higher pressures, since the latter was based on results with standard cable up to 30 pounds per square inch, the extension above this pressure being calculated from Paschen's law,[3] corrected for measured dielectric strength of nitrogen gas at the higher pressures.[4]

Working Voltage Stresses

The disagreement between calculated and measured results is not important, since even the measured curve in Figure 3 shows ionization voltage stresses at the higher pressures to be well above any working stresses that might be used in actual designs. For purposes of co-ordinated impulse strength the insulation thickness for a 138-kv high-pressure cable would correspond to an average 60-cycle working voltage stress of not more than 145 volts per mil. Figure 3 shows that even with a gas pressure as low as 80 pounds per square inch this working voltage stress is well below ionization voltage stress. At present, reinforced-sheath medium-pressure gas-filled cable operates at a pressure of 40 pounds per square inch and an average working voltage stress of 100 volts per mil. Reference to Figure 3 will show this to be well below the ionization-voltage curve. To a lesser degree, the same thing can be said of single-sheath low-pressure cable operating at 12 pounds per square inch and 65 volts per mil. In all three types there is room for further reduction in insulation thicknesses in the future, as far as 60-cycle voltage stresses are concerned. In this respect, no attempt has yet been made to take full advantage of the ionization self-extinguising characteristics of mass-impregnated gas-filled cable.

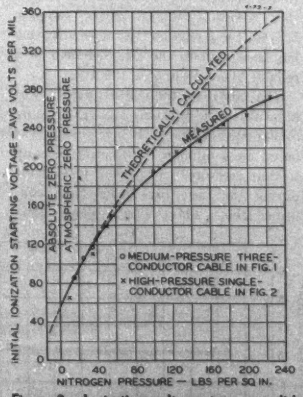
INITIAL IONIZATION STARTING VOLTAGE — AVG VOLTS PER MIL
ABSOLUTE ZERO PRESSURE
ATMOSPHERIC PRESSURE
THEORETICALLY CALCULATED
MEASURED
o MEDIUM-PRESSURE THREE-CONDUCTOR CABLE IN FIG. 1
× HIGH-PRESSURE SINGLE-CONDUCTOR CABLE IN FIG. 2
NITROGEN PRESSURE — LBS PER SQ. IN.

Figure 3. Ionization voltage stress on solid insulation at which initial ionization starts in mass-impregnated gas-filled cable after drainage of surplus compound but before endurance test voltage is applied

Automatic Grading and Self-Healing

Some engineers have questioned the fact that mass-impregnated cable is designed on the basis of average voltage stress rather than maximum stress and that comparative long-time load-cycle tests, as previously reported,[2] have shown no appreciable advantages for strand shielding or extra thin paper tape in the high-stress zone. These things appear to contradict theory, which tells us that the high-stress zone near the conductor is critical and needs to be strengthened by such expedients as strand shielding, thin paper tape, and limitations of maximum stress. These things have not proved necessary because of the pronounced ionization self-extinguishing characteristics of this type of cable, which is something that theory does not take into account.

This action may not yet be fully accounted for but recent studies have given a better understanding of it, as will be described. From the beginning, it has been understood that wax formation in the void spaces has had a good deal to do with extinguishing ionization discharge in its incipient stage and before it has had a chance to grow and become cumulative. The puzzling thing has been where all of the surplus compound came from that formed this wax, which completely or partially filled up the void spaces. This was not made clear until lengths of gas-filled cable impregnated with compounds covering a wide range of viscosities were subjected to long-time load-cycle tests and their behavior closely observed. It is now known that if the impregnating compound is of sufficiently low viscosity to be mobile it will be drawn into the high-stress field both by capillary action and by the electric stress field, itself. The voltage stress will also draw this compound into the low-specific-inductive-capacity voids and thus automatically rearrange the distribution of

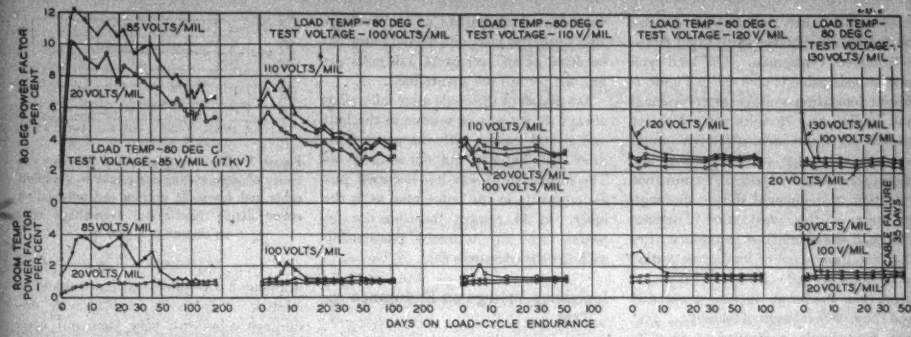
80 DEG POWER FACTOR — PER CENT
ROOM TEMP POWER FACTOR PER CENT
LOAD TEMP-80 DEG C TEST VOLTAGE-85 V/MIL (17 KV)
85 VOLTS/MIL
20 VOLTS/MIL
LOAD TEMP-80 DEG C TEST VOLTAGE-100 VOLTS/MIL
110 VOLTS/MIL
100 VOLTS/MIL
LOAD TEMP-80 DEG C TEST VOLTAGE-110 V/MIL
LOAD TEMP-80 DEG C TEST VOLTAGE-120 V/MIL
120 VOLTS/MIL
LOAD TEMP-80 DEG C TEST VOLTAGE-130 VOLTS/MIL
130 VOLTS/MIL
CABLE FAILURE 35 DAYS
DAYS ON LOAD-CYCLE ENDURANCE

Figure 4. Load-cycle endurance at ten-pounds-per-square-inch nitrogen gas pressure

Three-conductor gas-filled cable of standard construction, with exception that impregnating compound was thin number 5,314 oil having a Saybolt viscosity of 37 at 100 degrees centigrade, insulation thickness 0.200 inch

compound in the cable cross section to those locations where it is most needed. For convenience, this is termed automatic-grading action and the formation of wax, tending to fill up the voids, is termed self-healing action.

Both work together in preventing cumulative ionization in the high-stress zone and, in fact, throughout the whole cable cross section. Dielectric uniformity with absence of "weak spots" has always been an ultimate goal in high voltage cable practice. It is obtained in oil-filled cable by maintenance of oil pressure which, in turn, assures complete absence of voids.[5] In mass-impregnated gas-filled cable it is obtained by controlled gas pressure and the use of a mobile impregnating compound of optimum viscosity. Voids do form but their good behavior is assured by these automatic-grading and self-healing actions.

Load-Cycle Endurance Tests

Cable Impregnated With Thin Oil

These actions were first made clear by the surprising results obtained on load-cycle endurance test with a length of three-conductor cable impregnated with relatively thin number 5,314 oil, such as used in oil-filled cable and having a Saybolt viscosity of 37 at 100 degrees centigrade. The results are charted in Figure 4, the methods of test duplicating in all details those described in the two previous papers.[1,2] The description of test will not be repeated here, except to state that the cable was of the low-pressure shielded type with 350,000-circular-mil unshielded compact sector conductors, 0.200-inch insulation, and single lead sheath.

As would be expected, there was very pronounced drainage of this thin oil from the cable structure before leading, the outer surface having a dry appearance, with only that oil held in the denser parts of the cable cross section by capillary attraction being present. The extreme drainage and relatively large size of voids was verified by the initial power factor measurements at ten pounds per square inch, the initial ionization starting voltage stress being only 48 volts per mil, which is much below average standard results as given in Figure 3.

Figure 4 shows that during the first ten days of the first endurance step at 85 volts per mil there was pronounced

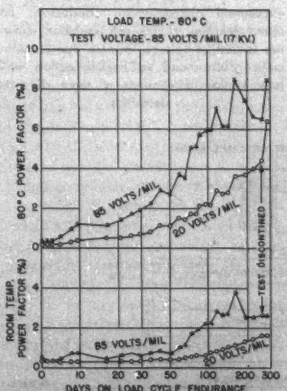

Figure 5. Load-cycle endurance at ten-pounds-per-square-inch nitrogen gas pressure

Three-conductor gas-filled cable of standard construction, with exception that impregnating compound was a heavy hydrogenated oil having a Saybolt viscosity of 1,000 at 100 degrees centigrade, insulation thickness 0.200 inch

ionization and instability. It was so marked that early failure of the cable length was expected. From this time on, however, the cable gradually improved. At the end of 125 days ionization had disappeared, due to closing up of the critical voids. When stability was assured after 189 days the life-test voltage was increased to 100 volts per mil. Ionization and instability were much less marked and disappeared after 95 days, the next voltage step being started after 103 days. These voltage steps were continued with the same results until final failure occurred after 48 days at 130 volts per mil.

The important point to note is that this cable showed even more self-healing ability than standard cable impregnated with heavier oil. Its endurance with final failure at 130 volts per mil, was also as good as the best results obtained with standard cable on these long time tests.

Dissection of the cable after test showed no evidence of the original thin oil. The paper tapes were quite dry and the butt spaces were completely filled with a gummy oil residue, representing that stage of polymerization before final *X* wax is formed. This residue was less gummy and more nearly resembled *X* wax as the conductor was approached. The strand spaces at the unshielded conductor were completely filled with a residue that was practically in the form of final *X* wax. The evidence was quite plain that most of the thin oil left in the paper tapes had been drawn into the low-specific-inductive-capacity voids by electric-field forces and had also been drawn towards the conductor, the paper tapes in the inner zone being less dry than those in the outer zone.

Cable Impregnated With Extra-Heavy Compound

Just the opposite results were obtained with a duplicate length of cable impreg-

nated with a very heavy hydrogenated oil having a Saybolt viscosity of 1,000 at 100 degrees centigrade. The load-cycle test on this cable is charted in Figure 5. Initial ionization voltage after drainage and leading was 75 volts per mil at ten pounds per square inch, which is a normal average value for standard cable and shows good initial impregnation and good retention of compound during drainage. In spite of this good start, however, Figure 5 shows marked instability after the first three days of load-cycle testing at 85 volts per mil. Dielectric losses and ionization discharge increased steadily and there were no signs of stability. Test was, accordingly, continued at 85 volts per mil for 277 days and since there were still no signs of ionization being extinguished, and stability reached, the test was stopped without attempting to go to a higher voltage step.

Dissection of the cable after test showed dry *X* wax deposits in the butt spaces throughout the cross section of insulation. These deposits became more pronounced at the inner layers of paper and at the unshielded conductor surface, showing a relationship to the electrical stress field. The void spaces were not, however, completely filled with this wax.

Cable Impregnated With Standard Compound

Typical load cycle endurance charts on gas-filled cable impregnated with standard number 5317 oil, having a Saybolt viscosity of 100 at 100 degrees centigrade were included in the two previous papers[1,2] and will not be repeated here. Initial ionization voltage of standard cable is given in Figure 3. On long-time load-cycle endurance, ionization has always been extinguished at each voltage step until the last, and final failure has occurred at an average of 120 volts per mil, ten pounds per square inch.

Dissection of the cable after failure has always shown wax or residue in the butt and strand spaces, with the paper tapes drier than initially, but not entirely so. The formation of wax has occurred just as frequently in the outer zone as in the inner. In this respect, there has not appeared to be any noticeable relationship with the electric-stress field.

Ionization Voltage on Endurance Test

At intervals of three or four days during the load-cycle endurance runs, just described, power-factor curves were measured over a sufficient voltage range to determine ionization starting voltage at that particular stage of the test. The results with the three different types of impregnating compound already described are charted in Figure 6. These three charts are of particular interest, since they give a direct measurement of critical void size at each stage of the load-cycle test from start to finish, and clearly bring out the automatic-grading and self-healing effects in mass-impregnated gas-filled cable as a function of compound viscosity. Charts *a* and *c* in Figure 6 correspond to Figures 4 and 5, relating, respectively, to load-cycle endurance runs with very thin and very heavy impregnating compounds. Chart *b* in Figure 6 corresponds to Figure 6 in the previous paper,[2] with standard number 5317 impregnating compound of intermediate viscosity.

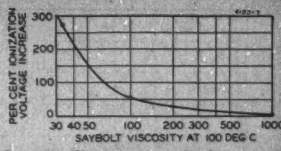

Figure 7. Showing relationship between viscosity of impregnating compound in gas-filled cable and automatic grading and self-healing action during load-cycle overvoltage tests as charted in Figure 6

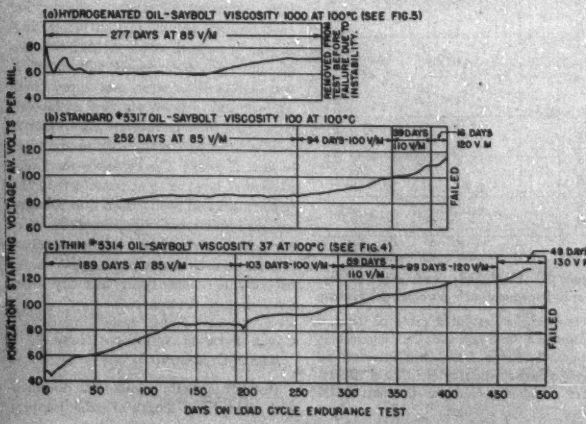
(a) HYDROGENATED OIL-SAYBOLT VISCOSITY 1000 AT 100°C (SEE FIG.5)
277 DAYS AT 85 V/M
REMOVED FROM TEST WITHOUT FAILURE DUE TO INSTABILITY.
(b) STANDARD #5317 OIL-SAYBOLT VISCOSITY 100 AT 100°C
252 DAYS AT 85 V/M
94 DAYS-100 V/M
39 DAYS 110 V/M
16 DAYS 120 V M
FAILED
(c) THIN #5314 OIL-SAYBOLT VISCOSITY 37 AT 100°C (SEE FIG.4)
189 DAYS AT 85 V/M
103 DAYS-100 V/M
29 DAYS 110 V/M
99 DAYS-120 V/M
48 DAYS 130 V M
FAILED
IONIZATION STARTING VOLTAGE-AV. VOLTS PER MIL.
DAYS ON LOAD CYCLE ENDURANCE TEST

Figure 6. Load-cycle endurance test on three-conductor cable at ten-pounds-per-square-inch nitrogen gas pressure, 350,000-circular-mil compact-sector conductors, no strand shielding, 0.200-inch insulation, showing ionization voltage increase due to automatic grading and self-healing action with impregnating compounds of three different viscosities

Chart *a* shows that while very good initial impregnation was obtained with the high-viscosity hydrogenated oil, this cable was unstable from the start and had no self-healing properties at all, ionization starting voltage dropping below the initial value and never fully recovering. After 277 days at 85 volts per mil there was still a pronounced ionization discharge in this cable. It is possible that compounds of other types and of equally high viscosity would give better results, but it is our conclusion that impregnating compounds of extra-high viscosity have little if any self-healing properties in gas-filled cable and are undesirable.

Chart *b* in Figure 6 is typical of standard cable. The cable did not drain objectionably before leading and initial ionization voltage was normal. The cable shows stability from the start, with a steady self-healing action that extinguishes ionization at each voltage step until the last. In no case did ionization voltage drop below the initial value. On the last voltage step cumulative ionization finally predominated and failure occurred after 16 days at 120 volts per mil.

Chart *c* in Figure 6 indicates that while very thin oil imparts remarkable self-healing properties to gas-filled cable there is too much drainage of this oil from the insulation and initial ionization voltage is too low, being only 48 volts per mil at ten pounds per square inch, well below normal operating stress of 65 volts per mil. This caused instability at the start of the load-cycle endurance run, but automatic grading and self-healing action eventually overcame this and the cable settled down to a surprisingly long endurance run, ionization being extin-

guished at each voltage step until final failure at 130 volts per mil.

Figure 6 plainly shows a relationship between viscosity of impregnating compound and the ability of the cable to extinguish ionization discharge. This is made clearer in Figure 7, where the increase in final ionization voltage, at the end of the endurance run, over the initial value is given as a function of compound viscosity.

Summary of Conclusions

Further laboratory and field studies of gas-filled cable confirm that gas-pressure control gives very close control of performance characteristics.

Over the usual commercial range of conductor sizes and insulation-wall thicknesses, average stress rather than maximum stress determines performance of mass-impregnated gas-filled cable, and it is not necessary to specially strengthen the inner zone of insulation in the high-stress field near the conductor.

Strand shielding of mass-impregnated gas-filled cable has shown no marked benefit but since it is in no way objectionable it can be used when desired.

Extra thin paper tape in the high-stress field has shown no marked benefit in mass-impregnated gas-filled cable and its added cost and complications do not appear justified.

Extra-high-viscosity impregnating compound lacks self-healing properties and should not be used in gas-filled cable.

Thin impregnating oil has remarkable self-healing properties but drains too readily for safe use in gas-filled cable.

Optimum results are obtained with an intermediate impregnating compound of sufficiently high viscosity to be held in place by capillary attraction without draining objectionably but, at the same time, of sufficiently low viscosity to have mobility. Our experience has indicated that a Saybolt viscosity in the order of 100 at 100 degrees centigrade gives the best results.

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4. The Electrical Strength of Nitrogen and Freon Under Pressure, H. H. Skilling and W. C. Brenner. AIEE Transactions, volume 61, 1942, April section, pages 191–5.

5. Characteristics of Oil-Filled Cable, G. B. Shanklin and F. H. Buller. AIEE Transactions, volume 50, 1931, pages 1411–20.

A New Frequency Relay for Power-System Applications

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Typical Applications

Loss of Tie-Line Overloading Plant Generation

THE interconnection of large power systems with industrial and defense plants having a comparatively small generating capacity is not unusual in these days. These plants require a considerable block of power for 24-hour full-capacity operation, and this power is available by means of the interconnection with the power system. More than one interconnection would assure higher continuity of service, but the general practice of locating defense plants in rural or suburban areas, remote from urban power-system networks, often results in one transmission-line interconnection operating in parallel with plant generators. Like all lines, the interconnection is subject occasionally to faults with resulting temporary loss of power for the plant. During these emergencies, the local generator or generators at the plant which normally contribute to the total load are suddenly called upon to carry all of the plant load. The local generators are not able to supply this load and consequently are heavily overloaded. As a result, the frequency decreases rapidly. However, complete shutdown of the plant can be avoided by dropping some of the load and retaining within the capacity of the local generators the load of the most essential machines and processes.

Thus, a reliable scheme is required to disconnect the load of the less essential feeders when the interconnection power is lost and the plant generators become overloaded. One scheme in general use is the application of an underfrequency relay in conjunction with reverse power relays. A typical system of this type is illustrated in Figure 1. When the power in the tie line decreases to a minimum, or reverses, and when the generator is overloaded as indicated by a drop in frequency, an auxiliary tripping relay is energized to disconnect the less essential feeders 1 through 4. Then the local generator can supply power to the more important feeders 5 and 6.

At the same time, the auxiliary relay also trips the tie breaker with the power system to prevent feedback of the local power to the power system. In the case of a fault on the interconnection line, the tie-breaker protective relays should complete the trip circuit ahead of the reverse-power and underfrequency relays. In this case, these latter relays operate as backup relays for the tie breaker. When power is available again via the interconnection, the two systems may be resynchronized, and the plant operator can restore the disconnected load in the proper operating sequence.

The measure of plant-system overload in this application is frequency change. The relay should respond to this change with a minimum variation in calibration because of voltage or temperature changes. The relay should be sensitive to frequency changes, operating fast for large changes in frequency and slower for small changes. Time delay is necessary to assure that the frequency relays

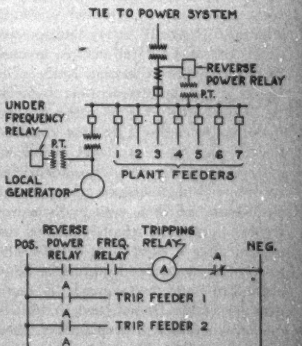

Figure 1. Single-line diagram of local power plant provided with frequency relays for disconnecting load

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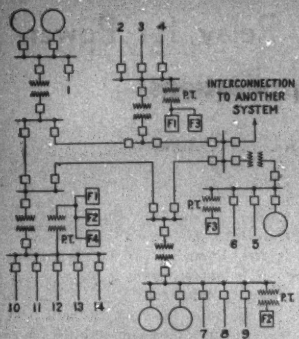

Figure 2. Single-line diagram of power system with frequency relays set for selectivity

Underfrequency Relays
(Normal Frequency—60 Cycles)

Symbol	Setting	Trip
F1	59.5 cycles	4 and 12
F2	59 cycles	9 and 14
F3	58 cycles	8 and 6
F4	57 cycles	10

operate only on sustained frequency changes, and not on changes resulting from faults which last only until the fault is cleared. For these reasons, an induction-type relay with inverse time characteristics is most suitable.

Loss of Generation on a Heavily Loaded System

Frequency relays can be used to disconnect load selectively on an overloaded system. A typical system consisting of several generating stations supplying local as well as remote loads is shown in Figure 2. Normally, this system operates at 60 cycles and near full capacity because of large increase in wartime loads. The loss of an important generating source or tie line or some other emergency system disturbance causes a sudden overload beyond the capacity of the remaining system, and the system frequency begins to drop. Underfrequency relays *F*1, set to operate at 59.5 cycles, disconnect feeders 4 and 12 at remote points on the system after a short time delay. The loss of this amount of load may be large enough to cause the frequency to return near 60 cycles. If not, and if the frequency continues to drop further, then frequency relays *F*2, set for 59 cycles, disconnect additional feeders 9 and 14 at other points on the system after more time delay. Again, the loss of this additional load may be enough to stabilize the frequency, but, if the frequency continues to drop, additional relays with lower-frequency settings disconnect more load. This process can be continued in a number of steps as dictated by the characteristics of the particular system and may be applied in the manner illustrated to drop varying amounts of load at a number of different stations.

Several relays may be set to operate at the same frequency value but to disconnect load at different time intervals. Thus, if the loss of the first block of load does not cause a definite rise in frequency, additional blocks of load would be dropped later, after suitable intervals of time. This has an advantage of only partially disconnecting the load assigned to be dropped at a particular frequency, if the frequency rises between the disconnecting intervals.

These schemes are not expected to replace dispatching or automatic load control, but provide a backup measure that can prove particularly valuable in holding important loads during an emergency. The scheme is applicable particularly to smaller systems such as are commonly found in rural areas, in large industrial plants, or a defense area whose overload capacity is limited, and may be exceeded by unpredicted increases in load.

The frequency relays in this scheme should be sensitive to changes in frequency, yet with a considerable range available for the selection of the operating frequency required in the various steps. In addition to the variable frequency setting, the relays should be capable of variable time settings over a wide range to permit selective timing of the various steps. As the relays may be located at different localities and operate under different conditions, it is desirable that the frequency relay have a minimum temperature and voltage error.

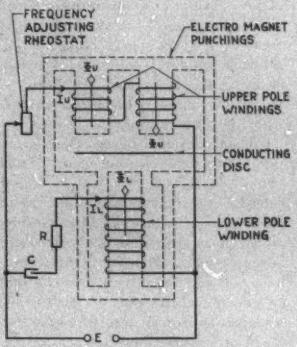

Figure 3. Schematic diagram of frequency relay

These applications of frequency relays discussed are typical and subject to variations and modifications required in each particular application. Other applications of frequency relays include overspeed or overfrequency protection of rotating equipment as well as underfrequency protection. The relays may not always be used only to trip circuit breakers, but also to give an alarm or warning of impending trouble.

Description of Relay

Relay Operating Principles

The preceding discussion has pointed out the operating requirements of typical systems using frequency relaying. These translate into several specific relay-performance requirements. The minimum trip-frequency variation of the relay should be small with respect to line-voltage change and with respect to ambient-temperature variation. The time and frequency setting of the relay should be easily adjustable over a wide range, and the time delay should be an inverse function of the frequency departure from normal system frequency. The relay described here satisfies these requirements and at the same time is quite simple in mechanical construction. Existing frequency relays use two electrical operating elements with opposing torques. The design described in this paper operates on an entirely different principle and utilizes only a single operating element.

In appearance, the relay is very similar to standard-type induction relays. It has the conventional rotating disk, time-lever scale, damping magnet, and a single electromagnet. Figure 3 is a circuit diagram of relay connections, and Figure 4 is a simplified vector diagram which illustrates the relay operation as either an under- or overfrequency device.

Essentially, the relay operation is comparable to that of a directional element. In Figure 4a, the upper-pole current, I_U, is shown lagging the impressed voltage, E. The lower-pole current, I_L, also lags the impressed voltage, but by an angle less than that of I_U. The lower-pole relay circuit, as shown in Figure 3, has inductance and capacitance in series, and, as the frequency increases, the lower-pole current becomes more lagging. Because inductive as well as capacitive reactance is present, the current in this circuit lags at a more rapid rate than the upper-pole current. At some frequency, the lower-pole current will lag sufficiently to be in phase with the upper-pole current. Under such

circumstances, the upper and lower fluxes of the relay are in phase, and there will be no torque on the induction disk. If the frequency now increases slightly, the lower-pole current and flux are rotated further in the clockwise direction, so that they lag the upper-pole quantities, and the induction disk will have a torque produced by the quadrature components of the upper- and lower-pole fluxes. The polarity of the overfrequency relay connections is so chosen that for ϕ_L leading ϕ_U, the relay has opening torque; then, when the frequency increases sufficiently for ϕ_L to lag ϕ_U, the torque of the relay reverses so that the contacts move in the closing direction. The larger the frequency increase beyond the zero-torque point, the greater the angular displacement between upper and lower fluxes, and the faster the relay operating time. Therefore, relay timing is inverse with respect to frequency changes.

The design is readily changed to an underfrequency circuit-closing relay by reversing the winding connection of either the upper or lower poles, which reverses the disk torques. To maintain open contact at normal frequency, the circuit constants are adjusted so that I_L lags I_U slightly, as shown by Figure 4b. As the frequency decreases, I_L advances, and, when it leads I_U, the contact closes.

The minimum trip frequency is determined by the point at which I_L and I_U are in phase; that is, zero torque. By changing the angle, with respect to the impressed voltage, at which this condition occurs, the frequency setting of the relay may be set as required. This angle is changed by adjusting the rheostat in the upper-pole circuit. Thus, in the case of the underfrequency relay, Figure 4b, as the resistance is increased, the upper-pole current lags less, so that a larger change in phase angle is required to swing I_L around to lead I_U. This corresponds to a lower minimum trip-frequency setting of the relay. A wide range of adjustment is easily realized by this means. Ten cycles is a typical frequency spread chosen.

Relay Operating Characteristics

The principles of relay operation already described permit the use of a single electromagnet and a mechanical construction which is easily adapted to the use of variable time-delay settings. These are obtained by the time-lever adjustments which permit variation of the moving-contact travel from a maximum of 180 degrees of rotation to a very small amount. Typical curves of relay operation for various lever and frequency settings are shown in Figure 5. These are taken for an instantaneous frequency drop. The wide range of settings available gives wide application limits.

The type of element described here inherently meets the requirement of minimum variation in tripping frequency with variation in impressed voltage. This may be seen if the relay is considered as a sensitive directional element operating near zero torque. At exactly zero torque, change in voltage will have no effect. The torque remains zero. Close to zero torque, the effect of voltage change on

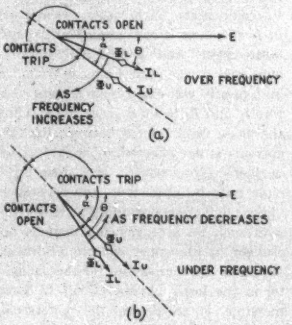

Figure 4. Vector diagrams showing principles of relay operation

the relay torque is still negligible, as shown in Appendix I.

The relay is extremely sensitive to frequency change. Consider the following equation for relay torque, and rate of change of torque

$$T = KI_L I_U \sin(\theta - \alpha) \quad (1)$$

$$\frac{dT}{d(\theta-\alpha)} = KI_L I_U \cos(\theta - \alpha) \quad (2)$$

where K is a factor of proportionality, and $\theta - \alpha$ is the phase angle between I_L and I_U. At zero torque, $\theta - \alpha = 0$. At this point the rate of change of relay torque with respect to phase angle is a maximum. Since $\theta - \alpha$ is a function of the frequency only, the relay will be at maximum sensitivity to frequency change.

The circuit elements of the relay are designed to make optimum use of the inherent sensitivity to frequency change and insensitivity to voltage change. The factors which determine the optimum design are the phase angle of the upper-pole circuit and the inductance and capacitance of the lower-pole circuit. The phase angle of the upper-pole circuit determines the angle at which zero torque occurs. The two extremes in design, occur for an angle of 0 degrees and an

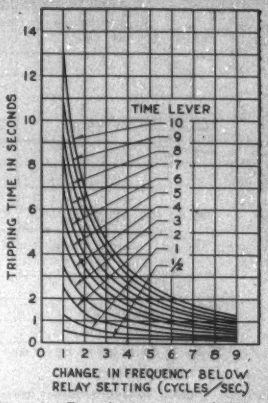

Figure 5. Typical time curves of 115-volt 50–60-cycle underfrequency relay

angle of 90 degrees. For the first case a large amount of external resistance is required to swamp out the inductive reactance of the relay coil, and hence only a small amount of operating ampere turns would be supplied the upper-pole windings. That is, the relay would not be a very sensitive directional element, so that this type of design is not satisfactory. The other extreme is for zero torque to occur at 90 degrees lag. Such a condition requires a purely reactive circuit, and the phase angle of such a circuit does not vary with frequency change. Thus, if any attempt were made to operate the relay with a zero-torque angle occurring near 90 degrees, the performance would be very unsatisfactory, since relay torque would respond in only small degree to change in frequency. It is apparent, therefore, that the phase angle of zero torque should be somewhere between these two extremes. An angle of 55 degrees is in fact the optimum one, and the relay is designed to operate near this value. This is more rigorously shown in Appendix II. With 55 degrees as the optimum zero-torque angle, the relative values of upper-pole circuit resistance and inductance are determined to be $R_U = 0.707\, X_U$.

The following considerations apply to the determination of the lower-pole-circuit constants. A circuit is required which changes vary rapidly in phase angle with respect to change in frequency. This is the case when a resistor is used in conjunction with reactive impedance whose magnitude varies very rapidly with frequency change. Such an impedance may be the series combination of inductance and capacitance. The re-

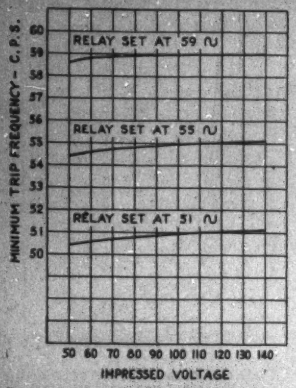

Figure 6. Typical voltage-frequency curves of 115-volt 50-60-cycle underfrequency relay

actance of such a combination is the difference $X_L - X_C$. Since X_L and X_C are inverse with respect to frequency variation, the difference will vary very rapidly if both X_L and X_C are very large and nearly equal. That is, the inductance of the lower-pole circuit should be as large as possible, and the capacitance as small as possible consistent with permissible burden and heating requirements. The resistance of this circuit is chosen approximately 0.707 times the net reactance so that the 55 degrees zero-torque-angle requirement is satisfied. Appendix II presents a more formal derivation of these requirements.

The variation of minimum trip frequency with respect to voltage change for a relay designed on the basis of the preceding criteria, is shown in Figure 6. For the complete range of settings, the frequency error is negligibly small for voltage variations from 50 to 140 volts. Note however that the errors are greatest

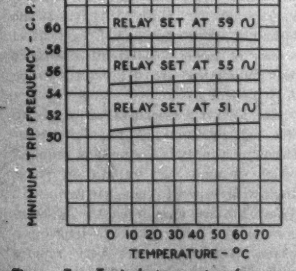

Figure 7. Typical temperature-frequency curves of 115-volt 50-60 cycle underfrequency relay

at the low-frequency settings. Here the largest value of upper-pole circuit resistance is required, and this represents the maximum departure from the optimum circuit requirements previously set forth.

The last consideration in determining the optimum design of the relay-circuit elements is the error due to ambient-temperature variation. This error can occur because of the variation of the inductive, capacitive, and resistive elements of the relay, with temperature. Since these variations cannot be eliminated entirely, the circuits must be designed so that the various changes tend to compensate each other. Variation in L of course is very small, and, since both upper- and lower-circuit inductance vary at the same time, any change in L merely will cause both current vectors I_L and I_U to rotate together. Thus the phase displacement between the two currents is not affected appreciably, and negligible errors result. This same principle may be applied to the resistance variation of the coil windings. However, with such an arrangement, there is no element in the upper coil circuit whose variation will compensate for the capacitor in the lower circuit. What is done therefore is to design the lower-pole winding with as small a coil resistance as possible relative to the upper-pole coil resistance. The physical construction of the electromagnet makes this relatively simple. The additional resistance placed in series in the lower-pole circuit to give optimum power factor produces a swamping action so that the over-all temperature variation of resistance in the lower-pole circuit is small. As the upper-pole resistance varies with temperature change (assuming negligible change in lower-pole circuit resistance) the vector I_U is swung around slightly. The direction is more lagging if the temperature decreases and less lagging if the temperature increases. C, in Figure 4, is a capacitor with a small negative temperature coefficient. That is, as the temperature decreases, C increases and X_C decreases. As the temperature increases, X_C increases. Thus I_L swings in the lagging direction as the temperature decreases and in the leading direction as the temperature increases. That is, the lower-pole current vector follows the upper-pole circuit vector, and hence the phase angle between the two changes but slightly with temperature variation, so that the frequency error due to ambient change is small. Typical temperature curves for a relay designed as described are shown in Figure 7. These indicate that the temperature error has been eliminated to a large extent.

Conclusions

This paper describes a new frequency relay with inverse time delay which trips at an assigned frequency with negligibly small voltage and temperature errors. The time delay of the relay, as well as the minimum trip frequency may be independently adjusted within a wide band. These design characteristics make the relay very suitable for power-system applications in which frequency is used as the discriminating quantity.

Appendix I

The following derivation indicates the order of magnitude of relay torque variation with respect to voltage near minimum trip frequency.

List of Symbols

E = voltage impressed on relay

R_L, L_L, C_L = resistance, inductance, capacitance of relay lower-pole circuit

R_U, L_U = resistance, inductance of relay upper-pole circuit

X_L = lower-pole circuit reactance $= \omega L_L - \dfrac{1}{\omega C_L}$

X_U = upper-pole circuit reactance $= \omega L_U$

$\dot{Z}_L$ = lower-pole circuit impedance $= R_L + j\left[\omega L_L - \dfrac{1}{\omega C_L}\right]$

$\dot{Z}_U$ = upper-pole circuit impedance $= R_U + j\omega L_U$

I_L = lower-pole current

I_U = upper-pole current

θ = phase angle by which I_L lags E

α = phase angle by which I_U lags E

$\omega = 2\pi F$

F = minimum trip frequency

T = relay torque

K = constant of proportionality

Assuming negligible shift between relay fluxes and respective currents, the equation of the induction disk torque is as follows:

$$T = KI_U I_L \sin(\theta - \alpha) \tag{3}$$

where $\theta - \alpha$ is the angle between I_U and I_L. Note that for $\theta > \alpha$, T is positive; $\theta < \alpha$, T reverses. However, only the absolute value of $\theta - \alpha$ is considered in this discussion, so that it is equally valid for under- or over-frequency relays.

$$\theta = \tan^{-1}\frac{X_L}{R_L} = \tan^{-1}\frac{\omega L_L - \dfrac{1}{\omega C_L}}{R_L} \tag{4}$$

$$\alpha = \tan^{-1}\frac{X_U}{R_U} = \tan^{-1}\frac{\omega L_U}{R_U} \tag{5}$$

$$I_L = \frac{E}{Z_L} = \frac{E}{\sqrt{R_L^2 + \left(\omega L_L - \dfrac{1}{\omega C_L}\right)^2}} \tag{6}$$

$$I_U = \frac{E}{Z_U} = \frac{E}{\sqrt{R_U^2 + \omega^2 L_U^2}} \tag{7}$$

The variation of torque with respect to voltage is given by

$$\frac{\partial T}{\partial E} = \frac{\partial}{\partial E}\left[\frac{KE^2}{Z_U Z_L}\sin(\theta - \alpha)\right] \tag{8}$$

$$\frac{\partial T}{\partial E} = \frac{2EK}{Z_U Z_L}\sin(\theta - \alpha)$$

$$\frac{\partial T}{\partial E} = \frac{2KI_U I_L \sin(\theta - \alpha)}{E} = \frac{2T}{E} \tag{9}$$

At minimum trip, the torque is only that amount required to overcome relay spring tension. Thus the numerator of equation 9 is small and the denominator large, so that the variation of torque with respect to voltage is small.

Appendix II

The following derivations indicate optimum design requirements for the relay circuit elements:

The relay sensitivity is measured by the magnitude of torque variation with respect to ω. This should be as large as possible.

If we refer to equation 3

$$\frac{\partial T}{\partial \omega} = \frac{\partial T}{\partial I_L}\cdot\frac{\partial I_L}{\partial \omega} + \frac{\partial T}{\partial I_U}\cdot\frac{\partial I_U}{\partial \omega} + \frac{\partial T}{\partial(\theta - \alpha)}\cdot\frac{\partial(\theta - \alpha)}{\partial \omega} \tag{10}$$

From equations 4, 5, 6, 7, $\partial(\theta-\alpha)/\partial\omega$, $\partial I_U/\partial\omega$ and $\partial I_L/\partial\omega$ are evaluated. From equation 3, $\partial T/\partial I_L$, $\partial T/\partial I_U$, and $\partial T/\partial(\theta-\alpha)$ are determined. Collecting terms

$$\frac{\partial T}{\partial \omega} = KI_L I_U \cos(\theta - \alpha)\times \left[\frac{R_L\left(L_L + \frac{1}{\omega^2 C_L}\right)}{Z_L^2} - \frac{R_U L_U}{Z_U^2}\right] - KI_L I_U \sin(\theta - \alpha)\times \left[\frac{X_L\left(L_L + \frac{1}{\omega^2 C_L}\right)}{Z_L^2} + \frac{X_U L_U}{Z_U^2}\right] \tag{11}$$

At minimum trip $\theta - \alpha$ is small, so that the second term of equation 11 may be neglected. Hence if we set $\cos(\theta-\alpha) = 1.0$, and note that at minimum trip

$$\text{Cos}\,\theta = \cos\alpha = \frac{R_U}{Z_U} = \frac{R_L}{Z_L} \tag{12}$$

we have

$$\frac{\partial T}{\partial \omega} = KI_L I_U \cos\theta\left[\frac{L_L + \frac{1}{\omega^2 C_L}}{Z_L} - \frac{L_U}{Z_U}\right] \tag{13}$$

$\partial T/\partial\omega$, and hence the frequency sensitivity can be made large by choosing L_L large, C_L small, and Z_L small. That is, the inductive reactance ωL_L, and the capacitive reactance $1/\omega C_L$, must both be large, but the resultant reactance $X_L = \omega L_L - 1/\omega C_L$ should be small. This will mean that

$$\frac{L_U}{Z_U} \ll \left[L_L + \frac{1}{\omega^2 C_L}\right]\frac{1}{Z_L} \tag{14}$$

The optimum value of R_L is determined by differentiating $\partial T/\partial\omega$, the measure of relay sensitivity, and setting the derivative equal to zero. This determines maximum sensitivity with respect to R_L.

If we substitute equations 6 and 12 in equation 13

$$\frac{\partial T}{\partial \omega} = \frac{KEI_U R_L}{Z_L^2}\left[L_L + \frac{1}{\omega^2 C_L}\right] - \frac{KEI_U}{Z_U}\frac{R_L L_U}{Z_L^2}$$

$$\frac{\partial^2 T}{\partial \omega \partial R_L} = KEI_U\left(L_L + \frac{1}{\omega^2 C_L}\right)\times \left[\frac{1}{(R_L^2 + X_L^2)^{3/2}} - \frac{3R_L^2}{(R_L^2 + X_L^2)^{5/2}}\right] - \frac{KEI_U L_U}{Z_U}\left[\frac{1}{R_L^2 + X_L^2} - \frac{2R_L^2}{(R_L^2 + X_L^2)^2}\right] = 0$$

$$\left[L_L + \frac{1}{\omega^2 C_L}\right]\left[\frac{Z_L^2 - 3R_L^2}{Z_L^3}\right] - \frac{L_U}{Z_U}\left[\frac{Z_L^2 - 2R_L^2}{Z_L^2}\right] = 0$$

$$R_L^2 = Z_L^2\left[\frac{\left(L_L + \frac{1}{\omega^2 C_L}\right) - L_U\frac{Z_L}{Z_U}}{3\left(L_L + \frac{1}{\omega^2 C_L}\right) - 2L_U\frac{Z_L}{Z_U}}\right]$$

$$\text{Cos}\,\theta = \cos\alpha = \frac{R_L}{Z_L} = \sqrt{\frac{\left(L_L + \frac{1}{\omega^2 C_L}\right) - L_U\frac{Z_L}{Z_U}}{3\left(L_L + \frac{1}{\omega^2 C_L}\right) - 2L_U\frac{Z_L}{Z_U}}}$$

$$\text{Cos}\,\theta = \cos\alpha = \sqrt{\frac{1}{3}}\sqrt{\frac{1 - \frac{L_U}{Z_U}\cdot\frac{Z_L}{\left(L_L + \frac{1}{\omega^2 C_L}\right)}}{1 - \frac{2}{3}\frac{L_U}{Z_U}\cdot\frac{Z_L}{\left(L_L + \frac{1}{\omega^2 C_L}\right)}}} \tag{15}$$

But from equation 14

$$\frac{L_U}{Z_U} \ll \frac{L_L + \frac{1}{\omega^2 C_L}}{Z_L}$$

or

$$\frac{L_U}{Z_U}\cdot\frac{Z_L}{L_L + \frac{1}{\omega^2 C_L}} \ll 1$$

Therefore, the second radical of equation 15 is approximately equal to 1, and we have

$$\text{Cos}\,\theta = \cos\alpha \approx \sqrt{\frac{1}{3}}$$

$$\theta = \alpha \approx 54.7^\circ \tag{16}$$

Therefore, $\tan\theta = 1.414$ or

$$\sqrt{2}R_L = X_L = \omega L_L - \frac{1}{\omega C_L} \tag{17}$$

To indicate the accuracy of this approximation, suppose

$$\frac{L_U}{Z_U}\cdot\frac{Z_L}{L_L + \frac{1}{\omega^2 C_L}} = 0.25$$

which means that

$$\left(L_L + \frac{1}{\omega^2 C_L}\right)\frac{1}{Z_L}$$

is only a nominal amount larger than L_U/Z_U. Even under these circumstances, the value of θ calculated from equation 15 is 56.7 degrees, which indicates that the approximated value of 54.7 degrees is very close for design purposes.

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Modern Motive Power for the Sorocabana Railway

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THE Sorocabana Railway in inaugurating electric traction on its extensive meter-gauge system has selected the 87-mile-long double-track section between São Paulo and Santo Antonio in the State of São Paulo, Brazil, for the initial electrification. Twenty locomotives are being furnished to handle passenger, freight, and mixed trains with scheduled speeds of 35 miles per hour for passenger, and 30 miles per hour for freight and mixed trains over a mountainous terrain involving maximum grades of two per cent, and prevailing minimum radius curves of approximately 800 feet.

These locomotives are the largest and most powerful 3,000-volt d-c meter-gauge units built to date and are among the outstanding examples of design and construction embodying all welded fabrication of mechanical parts and assemblies for main-line passenger and freight locomotives. Ten are being furnished by the General Electric Company and ten by the Westinghouse Electric and Manufacturing Company, with the mechanical portion of all 20 built by the General Electric Company. In addition to the mechanical portions which are identical, much of the equipment as furnished by the two companies is either identical or physically and electrically interchangeable. Pantographs, traction-motor blowers, watt-hour meters, and high-speed *JR* circuit breakers are identical with all pantographs manufactured by the Westinghouse Company and all breakers manufactured by the General Electric Company. Traction motors and motor generator blower sets are interchangeable. General characteristics of the locomotives are given in Table I. General dimensions are shown by Figure 1, and general appearance by Figure 2.

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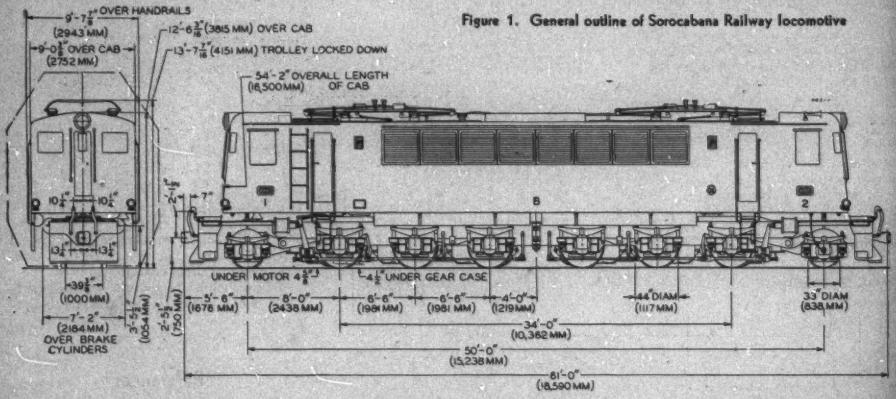


Figure 1. General outline of Sorocabana Railway locomotive

Running Gear

The running gear consists of two three-axle driving trucks (Figure 3) and two single-axle radius-bar guiding trucks (Figure 4). The driving-truck frames are articulated at their inner end by a ball joint arranged to permit angular movement in both vertical and horizontal planes. The outer ends extend over the guiding trucks and carry draft gear, coupler, and pilot. The frames are fabricated of steel plates and structural shapes throughout with all parts torch-cut to size requiring little or no machining (Figure 5). Side frames are universal mill-rolled open-hearth steel 3 1/2 inch thick, normalized, with an ultimate tensile strength of 55,000–65,000 pounds, maximum carbon content 0.25 per cent.

The guiding trucks are equipped with outside journals and rolled-steel wheels. Semielliptic and coil springs are arranged in series over the top of the journal boxes. A laterally movable bolster is provided on which a portion of the locomotive weight is carried through a system of equalizers extending from the springs over the outer driver boxes. The bolster is provided with a variable gravity-restraint device of relatively high initial restraint to steady the locomotive and minimize lateral oscillations when it is running on tangent track and to assist guiding of drivers negotiating track turnouts and curves (Figures 6 and 7). An extension of each guiding-truck inner frame serves as a radius bar connecting it to the main truck frame. These truck frames are also fabricated from torch-cut steel plates and structural shapes readily adapted to welding. The weight of the locomotive, with the exception of wheels, axles, journal boxes, and that part of the motors which is carried directly on the axles, is carried on a system of semi-elliptic and coil springs equalized to provide the desired loading on all wheels (Figure 8).

Cab Underframe

The cab underframe or platform is constructed of commercial steel shapes, bars, and plates. The structure is about 54 feet long by 9 feet wide. The center sills, which are the main load-carrying members of the frame, consist of two 18-inch

Figure 2. Three-quarter view of Sorocabana Railway locomotive

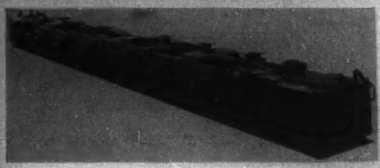


Figure 3 (left). Assembly of driving and guiding trucks complete

Figure 4 (below). Guiding truck

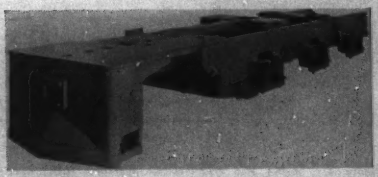


Figure 5. (right) Driving-truck frame

by 12-inch H beams reinforced with top and bottom plates of one-half inch thickness, forming a central duct serving as a pressure chamber into which air is discharged from two motor-operated blowers. From this chamber ventilating air is distributed to traction motors, accelerating resistors, and other electric apparatus. Side and end sills are made of eight-inch standard steel channels. Bolsters supporting center plates, side bearings, and lifting lugs are rigidly tied into center- and side-sill members. The 18-inch sill members extend well beyond the bolsters and are joined with eight-inch H beams (Figure 9) extending to ends of frame.

Cab

The cab is of semistreamlined design and is carried on two center plates located one on each of the two driving trucks. One of the center plates is arranged for sliding motion in the lower or truck socket to compensate for variations in truck center-plate distance when operating on curved track. Additional supports are provided through four spring-cushioned loading pads slideably supported, one on each side of each driving truck. The loading-pad springs are calibrated to give the desired load distribution on all driving and guiding wheels.

The cab consists mainly of exterior sheets 0.180-inch thick welded to a four-inch steel channel frame erected on the cab underframe. Louvres are provided in the side sheets of the central portion of the cab for ingress of air to the motor-blower sets. Large hatch openings are provided in the roof to facilitate installation and removal of apparatus and are closed by means of bolted-down hatch covers.

Apparatus Compartment

The apparatus compartment is built as a separate unit to facilitate easy installation of control apparatus and wiring. After the installation of apparatus and wiring is complete, the compartment is lowered through the hatch opening in the cab and is welded securely to the underframe and roof structure.

Construction Details

The locomotive design incorporates throughout the use of fabricated sub-

Table I. Characteristics of General Electric Locomotives for Sorocabana Railway

Classification 1−C+C−1−238/286−6 GE 734 A	3,000 volts
Length over-all, inside of coupler knuckles	61 feet, 0 inches
Width over-all	9 feet, 7 1/8 inches
Height over trolley locked down	13 feet, 7 1/16 inches
Track gauge	1 meter
Total wheel base	50 feet, 0 inches
Rigid wheel base	13 feet, 0 inches
Diameter driving wheels	44 inches
Diameter guiding wheels	33 inches
Total weight in running order	286,000 pounds
Weight on drivers	238,000 pounds
Weight per driving axle	39,666 pounds
Weight on guiding axles	48,000 pounds
Weight per guiding axle	24,000 pounds
Number of motors	6
Gear ratio	75/17
Continuous rating (horsepower)	1,910
One-hour rating (horsepower)	2,195
Continuous tractive effort (pounds)	24,475
One hour tractive effort (pounds)	29,500
Speed, continuous rating (miles per hour)	29.3
Speed, one-hour rating (miles per hour)	27.9
Maximum safe speed (miles per hour)	56

Figure 6. Guiding-truck bolster, center-plate extension, and parts of lateral-restraint device

Figure 7. Guiding-truck frame

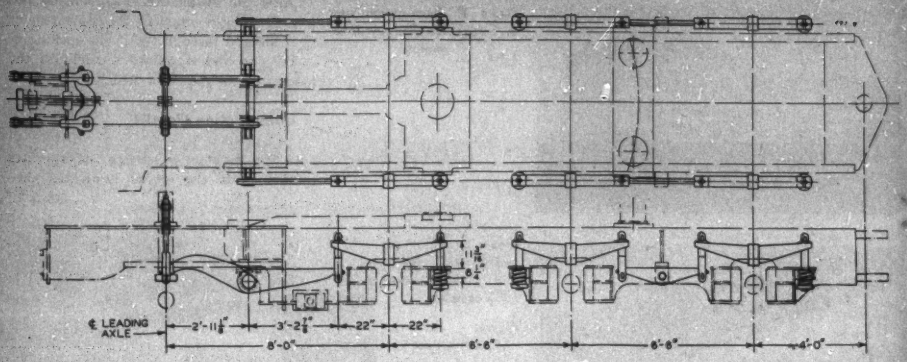


Figure 8. Spring and equalization system

assemblies which are easily handled for operations on the individual parts before being welded together for the complete assembly. All cross-tie plates fitting between side frames are machined to length with ends squared and are welded into subassemblies to facilitate the inner end frames for the articulation are performed in the subassembly stage.

After the truck frame is otherwise assembled and welded, pedestal shoes, forming guides for journal boxes, are set to position in a special fixture. Shoes are accurately trammed to position for squareness and distance, laterally as well as longitudinally, to the frame center as subassemblies after which they are set up and assembled with the cab platform which is itself a complete subassembly.

Air-Brake Equipment

The air-brake equipment is a combination of vacuum and compressed-air systems with the locomotive brakes operated

Figure 9. Cab underframe

Figure 11. Apparatus-compartment unit

easy setting up and squaring of the main truck frames. Each side frame, the articulation or inner end frame, the main-frame extension and other similar groups of parts are likewise fabricated to form finished subassemblies before final assembly together. The boring of the recess for the cab center plate in the middle cross tie and also the boring of the line extending through articulation, cab center plate, guiding-truck radius-bar fulcrum and center plate, draft gear and coupler. After accurate adjustments are accomplished the shoes are welded rigidly to the pedestal brackets. The cab sides, together with the cab frame, the hatches, cabinets, and compartments, likewise are first fabricated by compressed air and the train brakes operated by vacuum. The locomotive brakes may be operated independently of the train brakes, or in conjunction with them, in which latter case the train vacuum system acts as a pilot for the locomotive air-brake system. Two 12-inch-by-12-inch brake cylinders on each truck apply the brakes on that truck through a single brake shoe on each driving wheel. Interlocking is provided to prevent simultaneous operation of air brakes and regenerative braking to avoid

Figure 10. General arrangement of apparatus in cab

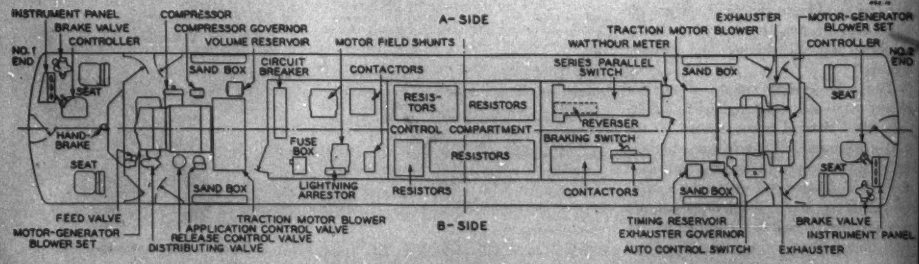


Figure 12. Traction-motor, wheel, and axle unit

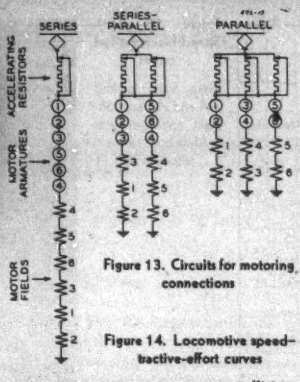
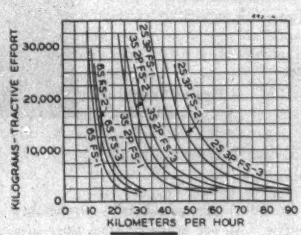


Figure 13. Circuits for motoring connections

Figure 14. Locomotive speed-tractive-effort curves



the possibility of wheel sliding during regenerative braking.

Location of Apparatus

The space between the operator's cabs is divided into three sections. The apparatus compartment, completely enclosed but with access doors and with removable covers along the aisles on each side, is in the center, while auxiliary apparatus such as motor generator blower sets, compressors, exhausters, and air-brake control devices are located at each end. The operator's cabs at each end of the locomotive are separated from the apparatus compartment by bulkheads with a door opening onto an aisle on each side of the locomotive (Figure 10). All apparatus is arranged to provide maximum accessibility for inspection and maintenance. Figure 11 shows the apparatus compartment complete with all equipment being lowered into place in the main cab through the hatch opening in the roof.

Electric Apparatus

Two spring-raised air-lowered pantographs are provided, either of which has adequate capacity for collecting total locomotive current from the 3,000-volt overhead line. The pantographs are equipped with antifriction bearings, and each has two separate contact shoes, independently hinged, to provide greater flexibility in maintaining contact with the overhead contact wire. A small reservoir which can be charged from the control air system is provided for maintenance of air pressure for unlatching the pantograph when both pantographs are down and no other air pressure is available on the locomotive. A small hand-operated air pump is also provided for this purpose. The two pantographs are connected together through a cable mounted on insulators on the roof and to the main power circuits through the protective

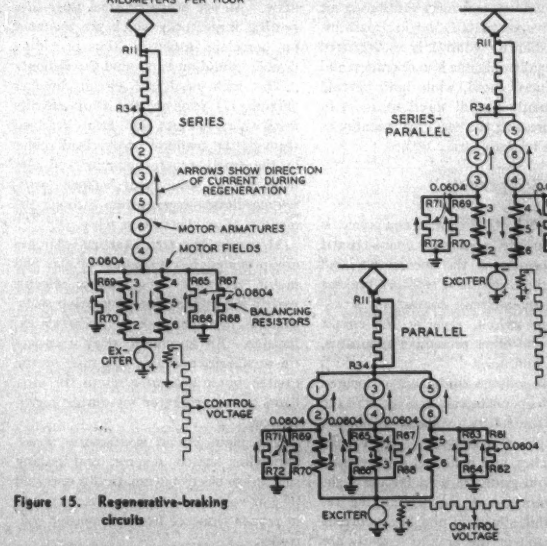


Figure 15. Regenerative-braking circuits

devices mounted in the apparatus compartment in the main cab.

The traction motors are wound and insulated for operation two in series on 3,000 volts and are of the commutating-pole force-ventilated type with antifriction bearings. Figure 12 shows a traction motor in place and suspended on the axle with gear case in place. Axle-suspension bearings are waste-packed, oil-lubricated. The drive consists of single-reduction gearing with a pinion on the motor shaft engaging a solid gear on the axle, both being enclosed in a gear case which also serves as a reservoir for the gearing lubricant.

The motor circuits are arranged for three combinations of motors: six in series, three in series with two such groups in parallel, and two in series with three such groups in parallel. Accelerating steps and one full-field and two reduced-field running steps are provided for each motor combination, thus making a total of nine running steps in motoring (Figures 13 and 14). Regenerative braking is provided for each of the three combinations of motors (Figures 15 and 16).

The auxiliary equipment duplicates that previously used on locomotives for the Paulista Railway, and consists of two 3,000/65-volt motor generator blower sets, two 65-volt exhausters, and one 65-volt compressor.

Each motor generator blower set consists of a single-commutator series-wound commutating-pole 3,000-volt motor, direct-connected to a 65-volt generator with a blower rotor overhung on an extended shaft from the motor end of the set. The generators of the two sets furnish power for the operation of control, lights, compressor, and exhausters, with one of the sets serving as an exciter

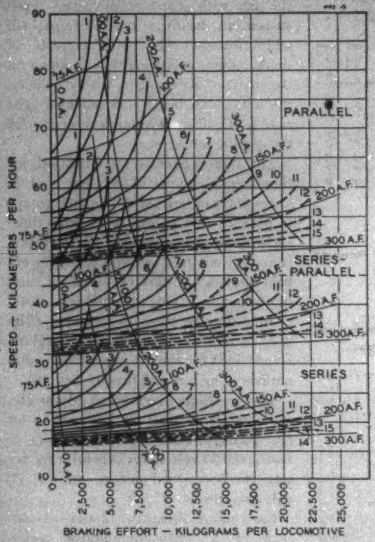


Figure 16 (left). Speed-braking-effort curves

Light lines marked *AA* and *AF* are constant armature- and field-ampere curves, respectively

Figure 17(right). *JR* circuit breaker

for traction-motor fields during regeneration. The blowers furnish ventilating air for all force-ventilated electric apparatus.

The exhauster control is so arranged that normally only one is in operation and at a reduced speed, while both operate intermittently at full speed to assist in quickly creating the necessary vacuum to effect the release of train brakes.

Control Equipment

The high-voltage control equipment is located in the apparatus compartment in the center of the locomotive and includes the accelerating resistors, braking resistors, main-circuit contactors, series-paralleling switch, reverser, *JR* circuit breaker, and other protective apparatus, switches, and fuses.

The low-voltage equipment is located in the two operating cabs and includes the master controllers, voltage regulator, pantograph magnet valves, control-circuit switches, and fuses and instruments.

Cast iron grids are used for the high-current sections of the accelerating resistors while those in the lower-current sections and in the braking circuits are formed of edge-wound strips of resistance alloy. All are insulated from their supporting frameworks which are mounted on porcelain insulators, thus providing double insulation to ground throughout.

The high-speed *JR* circuit breaker (Figure 17) protects the main circuits from short circuits and from overload through the medium of overload relays in the traction-motor circuits and also protects the equipment against overvoltage during regeneration through the medium of an overvoltage relay.

Manually operated starting switches are provided for operation of the two motor generator sets, and a selector switch is provided for alternative selection of the continuously operated exhauster. An automatic relay transfers the auxiliaries normally operating on the exciter motor generator set to the auxiliary motor generator set during regeneration.

The main circuit contactors, series-paralleling switch, reverser, and braking switch are electropneumatically operated by low-voltage control circuits energized in proper sequence from the master controller.

Each master controller is equipped with a main handle controlling accelerating and full-field running steps in motoring, a selector handle for selecting motor combinations for regenerative braking, a braking handle governing both regeneration and shunt-field steps in motoring, and a reverser handle for selecting direction of motion of the locomotive. All handles are interlocked mechanically to prevent improper operation and are conveniently located and in easy reach of the operator.

The instrument panel is mounted beneath the front window, directly in front of the engineer, and contains a line voltmeter, traction-motor field ammeter, traction-motor line ammeter, locomotive speed indicator, vacuum-brake gauge, and an air-brake gauge, illuminated indirectly from the rear of the panel.

The air- and vacuum-brake valves are on the right of the operating position, the master controller on the left. Bell-ringer and sander valves, control push buttons and valve for the pneuphonic horn are all mounted so as to require a minimum of movement on the part of the engineer. A record of power consumed during motoring and of power returned to the line when regenerating is obtained by means of a duplex watt-hour meter.

Voltage Transients in Arc-Furnace Circuits

AIEE SUBCOMMITTEE ON TRANSIENT VOLTAGES IN ARC-FURNACE CIRCUITS

THE subcommittee on transient voltages in arc-furnace circuits was established about four years ago to investigate the magnitude, cause, and control of transient voltages occurring at the primary and secondary terminals of arc-furnace transformers. The subcommittee has sponsored a number of field investigations during the past four years with the cooperation of steel companies, manufacturers of furnace equipment, and electric-equipment manufacturing companies. Only a part of the data obtained has been made generally available through publication (see a paper by Z. R. Whitehouse and C. C. Levy, "Surge-Voltage Tests on Electric Steel Arc Furnaces," presented at a joint meeting of AIEE and Association of Iron and Steel Engineers in Canton, May 1941, and also published references 1, 2, and 6). A data group of the subcommittee (L. W. Clark, chairman; S. B. Griscom, and E. R. Whitehead) was instructed to assemble all of the data available from the several field investigations, correlate the data as completely as possible to make them available for further study by the subcommittee, and prepare general conclusions regarding the magnitude of voltage transients found during the investigations. This paper summarizes the work of the data group and the preliminary findings of the subcommittee. It should be emphasized that this paper forms only a preliminary report of the work to date and is presented only so that the field data may be available for further study and analysis. The work of the subcommittee is continuing, not only in the collection and analysis of field data but also in experimental laboratory investigations and analytical analyses. It is expected that more definite recommendations regarding operating practices and possible protection schemes will be made after further study.

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Personnel of subcommittee on transient voltages in arc-furnace circuits: J. E. Hobson, *chairman;* E. R. Whitehead, *secretary;* S. Arnold, E. W. Boehne, F. W. Brooke, L. W. Clark, L. E. Ferri, L. Fountain, C. M. Foust, S. B. Griscom, J. B. Hodtum, W. B. Kouwenhoven, C. C. Levy, W. E. Moore, J. O. Shimmin, N. R. Stansel, *past chairman;* F. J. Vogel, H. H. Wagner.

Installation Data

Table I lists the essential information concerning the 15 furnaces tested at 12 different locations, with references to the key-system diagram in Figure 1. The rated temperature rise as well as the kilovolt-ampere rating of the furnace transformer has been listed in order that the true thermal rating of the transformer be known. All of the installations except two were 55-degree-rise transformers. The two transformers rated at 40 degrees and 45 degrees rise, respectively, are thus proportionately larger than those with the same kilovolt-ampere rating at 55 degrees rise.

Transformers for the most generally used single-phase arc furnaces are in the 125-volt class, single-voltage operation, voltage range 90–125 volts.

Transformers for three-phase arc furnaces are in the 250-volt class, multiple-voltage operation. The maximum voltages are within the range 220 to 300 volts. Although the maximum voltages of large units are seldom below 250 volts, the voltages in the upper part of the range given are often used for small units. The selection of maximum voltage does not follow a size classification.

The grounding practice appears to be practically uniform. In all cases except one, the transformer tank and furnace shell are grounded and the secondary circuit is grounded through lamps. The data collected on the secondary-bus installations were incomplete, and only at 3 out of 12 installations was the actual spacing of the bus obtained.

Table II lists all essential data regarding the power supply to the furnace transformer. Sufficient information has been collected on the installations so that it should be possible to estimate the capacitance to ground of that part of the power-supply system directly affecting the furnace operation. Several of the tests indicate that the characteristics of the power-supply system may have a considerable effect on the magnitude and number of voltage transients experienced. It is desirable to have the power-supply data available for further study as to its possible effect upon the transients.

An indication is given as to whether or not there have been insulation failures on either the line or transformer side of the transformer breaker, or on the secondary bus. However, there is no definite assurance that voltage transients have caused each of these failures.

Test Data

Table III gives most of the test data collected at the different installations. The recording device in most cases was a Lichtenberg figure recorder which records both the magnitude and number of transients. In one of the tests a cathode-ray oscillograph was used, and in another test a vacuum-tube counter was used to record the number of transients that occurred above a certain magnitude.

Most of the tests were made with the recorder on the transformer side of the furnace breaker, but in a few cases the recorder was on the line side of the furnace breaker. Also, in most cases the recorder was connected line to ground, although

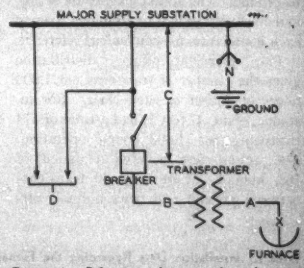


Figure 1. Schematic diagram of arc-furnace installation for reference—from Table II

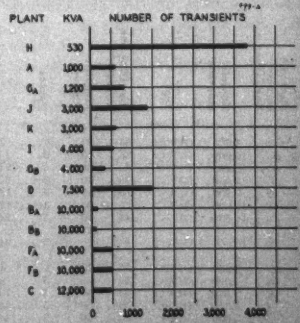


Figure 2. Total number of transient voltages per 1,000 hours of furnace operation plotted against furnace-transformer size

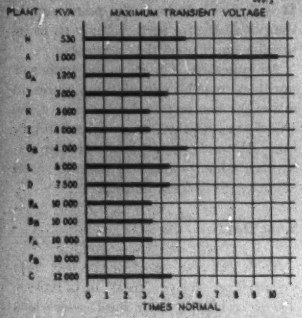


Figure 3. Maximum transient voltage (times normal voltage) plotted against furnace-transformer size

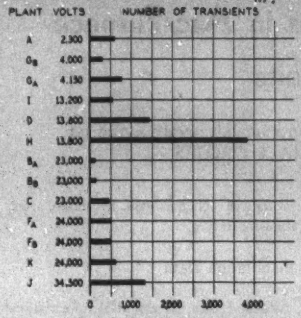


Figure 4. Total number of transients per 1,000 hours of furnace operation plotted against furnace-transformer primary voltage

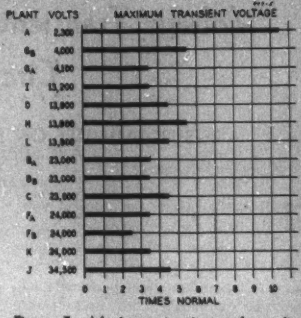


Figure 5. Maximum transient voltage (in times normal) plotted against furnace-transformer primary voltage

in a few cases it was connected line to line.

The transients recorded are segregated into groups according to magnitude. These groups are one to two times normal voltage, two to three times normal voltage, and so on, up to the highest group of 10 to 11 times normal. In all cases unless otherwise stated, this is crest voltage line-to-ground. The actual magnitude of normal crest voltage line-to-ground is given at each installation for convenient reference.

The transient-voltage distribution gives the number of transients per 1,000 hours operation in each class. For instance, plant *A*, test 1, had a total of 574 transients per 1,000 hours operation. The actual test covered a period of 768 hours. There were 30 transients between normal and twice normal voltage per 1,000 hours operation. In the top classification there were five transients per 1,000 hours operation in the 10 to 11 times normal-voltage class.

It was not possible to segregate the transient-voltage distribution for all tests; for instance, in test 2 at plant *A* it is known only that there were 77 transients between one and four times normal per 1,000 hours operation. Similarly, at installation *D* (tests 1, 2, and 3) it was not possible to give a complete breakdown. The tests at installation *E* were made with a vacuum-tube counter, so that the only information available is the number of transients in excess of 20 kv. For example, in test *E*—1, there were 33 transients per 1,000 hours of operation in excess of 20 kv, which is about twice normal voltage.

Test *E*—1 shows the relationship between number and magnitude of transients and breaker operations. The recording device was connected in such a way that it recorded transients only at the time the transformer breaker was closed or opened, and in this particular case 30 of 33 transients occurred at the time of closing the breaker, and only three occurred at the time of opening the breaker. There may have been other transients during normal operation of the furnace, but the equipment was not connected in such a way as to record them.

Test *E*—4 gives all of the transients during normal operation of the furnace, but an arcing ground developed in the cable feed to the transformer during the test, and it is believed that this caused the abnormal number of transients (1,660

Table I. Installation Data Regarding the Furnace Transformer, Circuit Breaker, Grounding, and Insulation of the Secondary Bus at Locations Where Tests Were Made

	Furnace Transformer					Voltage		Circuit Breaker			Grounding			Secondary Insulation		
Plant and Furnace Designation	Kilovolt-Amperes	Type	Rise (Degrees Centigrade)	Frequency (Cycles)	Phases	Primary Volts Delta	Secondary Volts Delta	Oil or Air	Amperes	Kilovolts	Interrupting Kilovolt-Amperes	Transformer Tank	Furnace Shell	Secondary Lamps	Spacing	Creepage	Material
A	1,000	OIWC*	55	60	3	2,300	230	Oil				Yes	Yes	Yes	Busses not interlaced		
Ba	10,000	OIWC	55	60	3	23,000	300	Oil	600	34.5	500,000	Yes	Yes	Yes	Busses interlaced		
Bb	10,000	OIWC	55	60	3	23,000	300	Oil	600	34.5	500,000	Yes	Yes	Yes	Busses interlaced		
C	12,000	OIWC	55	60	3	23,000	270	Oil	600	23		Yes	Yes	Yes	Busses interlaced		
D	7,500	OIWC	40	60	3	13,800	234	Air	600	15	250,000	Yes	Yes	Yes	Busses interlaced		
E	10,000	OIWC	55	60	3	11,000		Air	600	15	250,000	Yes	Yes	Yes	Busses interlaced		
Fa	10,000	OIWC	45	60	3	24,000	290	Oil	600	23	100,000 at 15 kv	Yes	Yes	Yes	1/2 inch	9/16 inch	Micarta
Fb	10,000	OIWC	55	60	3	24,000	240	Oil	600	23	250,000 at 15 kv	Yes	Yes	Yes	1/2 inch	9/16 inch	Micarta
Ga	1,300	OIWC	55	25	3	4,150	225	Oil				Yes		Yes			
Gb	4,000	OIWC	55	25	3	4,000	235	Oil				Yes		Yes			
H	530	OIWC	55	60	1	13,800	125	Oil		15		Yes	No	Yes			
I	4,000	OIWC	55	60	3	13,200	225	Air	600	15	250,000	Yes	Yes	Yes			
J	3,000	OIWC	55	60	3	34,500	220	Oil	600	46	500,000	Yes	Yes	Yes	5/8 inch	5/8 inch	Bakelite
K	3,000	OIWC	55	60	3	34,000	235	Oil	600	34.5	500,000	Yes	Yes	Yes	5/8 inch	5/8 inch	Bakelite
L	6,000	OIWC	55	60	3	13,800	265	Oil		34	500,000	Yes		Yes			

* Oil-immersed water-cooled.

Table II. Power-System Data

Refer to Figure 1 for Key Diagram

Plant and Furnace Designation	Neutral Grounding Method	Transmission Data B Overhead	Transmission Data B Underground	Transmission Data C Overhead	Transmission Data C Underground	Transmission Data D Overhead	Transmission Data D Underground	Insulation Failures A	Insulation Failures B	Insulation Failures C	Remarks
A		40 feet	No	4,400 feet	No	No	No	No	No	No	Single circuit
Ba								Yes	No	No	
Bb								Yes	No	No	
C		No	90 feet	840 feet	390 feet	6,200 feet	3,200 feet	Yes	Yes	No	Single circuit—arresters at both ends of *C* 500,000 kva short circuit at *B*
D	Ungrounded	40 feet	60 feet	1,000 feet	No	No	No	Yes	Yes	No	Single circuit—184,500-kva short circuit at *B* 3—15 kva, 460-volt capacitors at *A* 3—1/4 microfarads 13.8-kv capacitors and three type *S V* 13.8-kv arresters at *B*
E	Ungrounded delta	No	No	No	705 feet	No	2.76 miles	No	Yes	Yes	Three parallel circuits in *C* 12-kv Westinghouse distribution arresters at *C* 198,500-kva short circuit at *B*
Fa	Solid ground	80 feet	No	1,300 feet	1,300 feet	1,125 feet	1,150 feet	Yes	No	No	Single circuit 850,000-kva short circuit at *B* Westinghouse type *L V* 500-volt
Fb											Arresters at *A* General Electric 24-kv—oxide-film arresters at *C*
Ga	Solid ground	50 feet	No	No	1,500 feet	No	3,000 feet				Single circuit 100,000-kva short circuit at *B*
Gb											No arresters
H	8 ohms resistance	No	400 feet	2.4 miles	No	12.4 miles	2.9 miles	Yes	No	No	Single circuit 15-kv line-type arresters at *C* 120,000-kva short circuit at *B*
I	2.5 ohms resistance	No	100 feet	No	1,700 feet	No	25				Single circuit—no arresters 131,500-kva short circuit at *B*
J	Petersen-coil tests 1, 2, 4; solid ground test 3			4 miles	650 feet	350 feet	No	No	No	Yes	Oxide film arrester at *C* Underground cable at *C* bypassed by overhead for test 4
K	Solid ground	No	No	4 miles	No	No	No	No	No	No	25-kv "porous block" autovalve arrester at *C*
L	2 ohms resistance	No	0.25 mile	3 miles	16 miles	11 miles	165 feet	No	No	Yes	*B*-2 circuits, 2 cables each *C*-4 circuits, 2 cables each 26-kv deion tubes on one phase at *C* 550,000-kva short circuit at *B*

transients per 1,000 hours). There is a somewhat similar comparison between tests *E*—2 and *E*—3, except that it should be noted that the recording device on these tests was on the line side of the breaker. During test *E*—2, there were 11 transients (per 1,000 hours of operation) above twice normal during normal operation; when the recorder (test *E*—3) was connected to record transients only at the time of closing or opening the breaker, no transients were recorded.

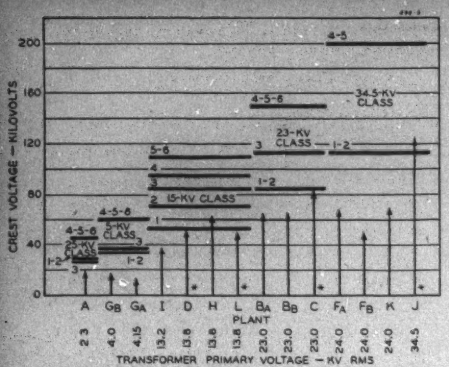
Tests at the *J* and *K* installations also give some information as to the effect of switch openings and closings on the transients. For instance, test *J*—1 shows 1,316 transients per 1,000 hours of operation, and during the test of 250 hours there were 700 switch operations. This indicates a total of 2,800 switch operations for the 1,000-hour period, and 47 per cent of the switch operations could have caused transients. However, test *J*—2 recorded transients only at the time of staged switching operations; and for 672 staged operations there were 315 transients which is also 47 per cent of the operations. This is at least an indication that most of the transients on the transformer side of the primary breaker at this installation occurred at the time of a switch operation.

A similar comparison for tests 1 and 2 at location *K* shows that under normal operating conditions there were transients for 30 per cent of the switch operations and that for the staged switching operations there were transients recorded on 34 per cent of the switching operations. These tests seem very definitely to link the number of primary transients recorded to the number of switch operations.

Under column headed "Test Conditions," an indication is given as to whether the test was conducted under normal operating conditions or under some special condition with perhaps some remedial measures having been taken or some form of corrective equipment added. Tests 1 to 8 at location *D* show the effect of various combinations of arresters, capacitors, and reactors. For instance, with no remedial measures there were 1,460 transients per 1,000 hours operation, and with various combinations of corrective measures both the number of transients and their magnitude were reduced in varying proportions, depending upon the measures used. Similarly, at two tests, *J*—2 and *J*—3, Petersen-coil grounding was replaced with solid grounding, showing both a slight reduction in the number of transients and a slight reduction in the magnitude of the transients. However, the greatest reduction occurred when a 650-foot length of cable in the primary feed to the installation was replaced with overhead, as shown in test *J*—4. This indicates that the electrical characteristics of the circuit have a definite effect on the magnitude and number of transients.

There are only two installations at which transient measurements were made on the secondary circuit of the furnace transformer. These data are summarized in Table V. At location *F* measurements were made on two 10,000-kva furnaces and at location *H* on a single-phase 530-kva furnace. The number of hours operation for the test at location *H* is unknown, so the number of transients could not be reduced to a 1,000-hour operation basis.

The secondary transients are divided into classifications reading directly in kilovolts rather than times normal. It is



Maximum transient voltage crest of 60-cycle one-minute test:
1—Apparatus bushings, small
2—Apparatus bushings, large
3—Air switches and bus supports

Impulse 1.5x40 full wave
4—Apparatus bushings, small
5—Apparatus bushings, large
6—Air switches and bus supports
* Insulation failures occurred

Figure 6. Maximum transient voltage appearing on primary winding of the furnace transformer compared with withstand test voltages of insulation for indoor equipment

thought that there would be little significance in classifying them on a times-normal basis where the actual secondary voltages vary only between 125 and 300 volts. The first column, for instance, in the transient-voltage distribution are those transients between 1 and 2 kv, 2 and 3 kv, and so forth, on up to the final column for the class 12 to 14 kv. Again the number of transients is given per 1,000 hours of operation.

Test *Fa*—3 covers 250 hours operation with the recorder located line to ground and with secondary arresters connected to the bus. There were no transients recorded during this period. Similarly, test *Fa*—6 gives a 720-hour run on the same furnace one year later with secondary arresters, and again no transients were recorded. However, test *Fb*—4 gives the number of transients recorded on the secondary winding of another transformer of practically duplicate rating and fed over practically a duplicate circuit. The only difference is that there were no secondary arresters in the circuit. This test showed 86 transients per 1,000 hours operation with one transient as high as eight or ten-kilovolt crest voltage line-to-ground. Test *Fb*—5 is another test run on the same furnace under similar conditions but with secondary arresters added. This shows 72 transients, but the magnitude has been reduced, and the great majority of transients are in the one- to two-kilovolt class, none higher than the three- to four-kilovolt class, indicating considerable improvement due to the arresters.

About one year later a similar test run was made on the same furnace with the transient recorders connected line to line instead of line to ground, and a vacuum-tube recording device was added to indicate arrester operation. Magnetic links were placed in the arrester circuits to give a measure of the transient current passed by the arresters. The test was conducted for 720 hours, and no transients were re-

Table III. Summary of Test Data on Primary-Voltage Transients

Plant and Furnace Designation and Test Number	Recording Device 1, 2, or 3*	Recorder Location (Line-to-Ground)	Test Operating (Hours)	Furnace Size (Kilovolt-Amperes)	Normal Line Voltage (Rms)	Normal Line-to-Ground Crest Voltage	Total Transients Per 1,000 Hours	Transient-Voltage Distribution—Number of Transients Per 1,000 Hours Operation—Times Normal Line-to-Ground Crest Voltage									
								1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11
A—1	1	*B*	768	1,000	2,300	1,870	574	30	305	126	48	30	21	5	3	1	5
A—2	1	*B*	456	1,000	2,300	1,870	77	←	77	→							
Ba—1	1	*B*	1,000	10,000	23,000	18,700	81	7	64	10							
Bb—2	1	*B*	1,000	10,000	23,000	18,700	78	15	62	1							
C	1	*B*	840	12,000	23,000	18,700	420	118	161	36	4						
D—1	1	*B*	150	7,500	13,800	11,200	1,460	←	1,453	→	0	7					
D—2	1	*B*	48	7,500	13,800	11,200	417	←	417	→							
D—3	1	*B*	912	7,500	13,800	11,200	1,170	←	1,169	→	1						
D—4	1	*B*	3,960	7,500	13,800	11,200	540	475	56	9							
D—5	1	*B*	418	7,500	13,800	11,200	42	37	5								
D—6	1	*B*	1,056	7,500	13,800	11,200	125	117	8								
D—7	1	*B*	1,416	7,500	13,800	11,200	208	136	68	4							
D—8	1	*B*	696	7,500	13,800	11,200	292	236	56								
E—1	3	*B*	336	10,000	11,000	8,950	33	←			33	(30 out of 33 were on closing breaker)					
E—2	3	*C*	551	10,000	11,000	8,950	11	←			11						
E—3	3	*C*	336	10,000	11,000	8,950	0										
E—4	3	*B*	240	10,000	11,000	8,950	1,660	←		1,660							
E—5	3	*C*		10,000	11,000	8,950		←		1	(Staged test—automatic trip in single-phase short circuit)						
Fa—1	1	*B*	2,711	10,000	24,000	19,500	500	475	24	1							
Fb—2	1	*B*	713	10,000	24,000	19,500	478	465	13								
Ga—1	1	*B***	84	1,200	4,150	5,850**	107	72	35								
Ga—2	1	*B*	84	1,200	4,150	3,380	798	179	584	35							
Gb—4	1	*B***	168	4,000	4,000	5,640**	209	143	48	18							
Gb—5	1	*B*	250	4,000	4,000	3,250	292	108	124	44	12	4					
H—1	1	*B*	44	530	13,800	11,200	3,810	1,630	1,520	523	114	23					
H—2	1	*B***	44	530	13,800	19,500**	2,412	1,230	955	227							
J—1	1	*B*	72	4,000	13,200	10,800	528	472	55	1							
J—1	1	*B*	250	3,000	34,500	28,000	1,326	784	280	196	56						
J—2	1	*B*		3,000	34,500	28,000		188	67	47	13***						
J—3	1	*B*		3,000	34,500	28,000		60	23	6***							
J—4	1	*B*		3,000	34,500	28,000		25	8***								
K—1	1 and 2	*B*	150	3,000	24,000	19,500	600	480	100	20							
K—2	1 and 2	*B*		3,000	24,000	19,500		168	70	7***							
L—1	2	*B*		6,000	3,800	11,200		15	3	3	1***						

* 1. Lichtenberg figure. 2. Cathode-ray oscillograph. 3. Vacuum-tube counter. ** Line to line.
*** Actual number of transients—not per 1,000 hours of operation.

corded. As far as could be determined, there was no change in furnace operation from the test of a year previous when a large number of transients was experienced; the only known difference was that the recorders were connected line to line instead of line to ground.

There is nothing brought out by the secondary tests on these installations to indicate that there is any connection between secondary transients and primary-breaker operations. This installation had four cases of secondary-bus flashovers, all of which occurred during the normal heat run of the furnace at a time when the primary breaker was closed and the furnace was in normal operation, indicating that some of the transients at least are not associated with breaker operation.

Figures 2 through 5 are presented to give a visual indication of the possible existence of any uniform pattern or relationship among furnace size, primary voltage, and the number and magnitude of transients. In all cases the data used are those of tests made when no remedial measures were taken and no corrective equipment added. These charts show no trends nor any functional relationship existing between the previously listed variables. This tends to strengthen the previously expressed thought that electric-system characteristics are a predominant factor in the number and magnitude of transients.

Figure 6 shows the magnitude, in kilovolts, of the maximum transient measured for each test and its relation to the withstand test voltage of insulation for indoor equipment for each voltage class. The AIEE Standards for apparatus bushings of both large and small apparatus, and for air switches and bus supports specify certain withstand test voltages which are a measure of the basic insulation level for each voltage class of insulation. There are some inconsistencies in the values specified in the Standards for the different types of apparatus, but, in general, an insulation level can be indicated whose lower bound is the crest of the 60-cycle one-minute withstand test voltage, and whose upper bound is the impulse withstand test voltage. It is believed that the actual insulation strength against furnace transients of this type, although certainly variable, falls somewhere between these limits.

At the installations where insulation failures were recorded (plants *D*, *L*, *C*, and *J*), the maximum transients all approach or pierce the lower bound of the insulation level shown on the chart. In this connection it should be pointed out that complete information is lacking regarding the actual insulation levels existing at each test installation, and that, if materially lower levels are encountered, infrequent failures might be expected. Insulation levels recommended for general use in power installations also appear to be satisfactory for most furnace installations. For some devices there are "high" and "low" levels within the nominal voltage rating, and the "high" level should be selected (particularly when the operating voltage approaches the "voltage class"), or it may be desirable to use apparatus of a higher actual insulation level or to apply suitable protection equipment.

Table IV. Summary of Test Conditions

Plant and Furnace Designation and Test Number	Test Conditions
A—1	No remedial measures
A—2	High-voltage capacitor at *B*
Ba—1	No remedial measures
Bb—2	No remedial measures
C	No remedial measures
D—1	No remedial measures, no capacitors, no arresters
D—2	High-voltage arresters, no capacitors, 5.9 per cent reactor
D—3	High-voltage arresters, low-voltage capacitors, no reactor
D—4	High-voltage arresters, low-voltage capacitors, 5.9 per cent reactor
D—5	High-voltage arresters, high-voltage capacitors, 5.9 per cent reactor
D—6	High-voltage arresters, high-voltage and low-voltage capacitors, 5.9 per cent reactors
D—7	High-voltage arresters, high-voltage and low-voltage capacitors, no reactor
D—8	High-voltage arresters, high-voltage capacitors, no reactor
E—1	Transients in excess of 20 kv recorded; transients only at time of opening or closing breaker
E—2	Transients in excess of 20 kv recorded; normal operation all transients
E—3	Transients in excess of 20 kv recorded; transients only at time of closing or opening breaker
E—4	Transients in excess of 20 kv recorded; transients evidently caused by arcing ground in cable at *C*
E—5	Transients in excess of 20 kv recorded
Fa—1	Normal conditions
Fb—2	Normal conditions
Ga—1	Normal conditions
Ga—2	Normal conditions
Gb—4	Normal conditions
Gb—5	Normal conditions
H—1	Normal conditions
H—2	Normal conditions
I—1	Normal conditions
J—1	Normal conditions (700 switch operations); Petersen-coil grounding
J—2	672 staged switching operations; Petersen-coil grounding
J—3	206 staged switching operations; solid grounding
J—4	323 staged switching operations; Petersen-coil grounding; 650 feet of cable replaced with overhead
K—1	Normal conditions (300 switch operations)
K—2	700 staged switching operations
L—1	31 staged switching operations, opening magnetizing current

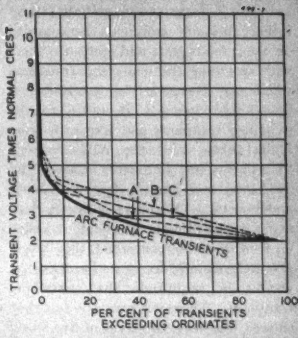


Figure 7. The distribution and magnitude of arc-furnace primary-voltage transients compared with switching and fault transient voltages

A and *C*—Switching transients
B—Transients from faults
From reference 4

Table V. Summary of Transient Voltages Recorded on Secondary Circuits

Plant and Furnace Designation and Test Number	Recording Device 1, 2, or 3*	Recorder Location Line-to-Ground	Test Operating (Hours)	Total Transients Per 1,000 Hours	Transient-Voltage Distribution—Number of Transients Per 1,000 Hours Operation—Crest Voltage in Kilovolts 1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-10	10-12	12-14	Test Conditions
Fa—3	1	*A*	250	0											With secondary arresters
Fb—4	1	*A*	1,028	86	40	26	13	4	0	1	1	1			With secondary arresters
Fb—5	1	*A*	530	72	64	2	6								With secondary arresters
Fa—6	1	*A***	720	0											With secondary arresters
Fb—7	1	*A***	720	0											With secondary arresters
H—3	1	*A*			1	2	2	4	5	6	10***	10	2	1	Normal operation

* 1. Lichtenberg figure. 2. Cathode-ray oscillograph. 3. Vacuum-tube counter. ** Line to line.

*** Actual number of transients—not per 1,000 hours of operation.

Figure 7 shows the magnitude of arc-furnace primary transients as recorded on the various tests and compares them with switching transients and transients which may be caused by system faults. The dotted curves *A*, *B*, and *C* are the switching transients and transients from faults taken from the AIEE paper,[3] "Power-System Transients Caused by Switching and Faults" (see also Lewis and Foust[6]). This curve indicates that, as far as the primary transients recorded on these tests are concerned, they are of about the same order as, and at least not greater in magnitude than switching transients. There was only one test that showed transients in excess of five to six times normal. Of all the transients recorded above twice normal, 92 per cent were less than four times normal voltage. This curve sheet does not bring out the known fact, however, that the frequency of occurrence of furnace transients can be many thousands of times greater than that of ordinary power-system transients.

Summary

1. Voltage transients encountered in primary circuits of furnace transformers have characteristics similar to those of ordinary power-system voltage transients, except that of frequency of occurrence. Primary-circuit transient overvoltages in arc-furnace installations occur during the melting-down operation and at the time of opening or closing the furnace breaker. The highest magnitudes appear to be associated with breaker opening operations. Accordingly, there are more transients in furnace transformer circuits over a given period of time, because furnace breakers operate 40 to 50 times per day compared to a few times a year for the general use of circuit breakers.

2. Insulation levels recommended for general use in power installations also appear to be satisfactory for most furnace installations. For some devices, however, there are wide variations of the insulation level for the same voltage rating, and in those cases where the operating voltage approaches the "voltage class," it may be desirable to use apparatus of a higher actual insulation level as compared to the rating or to apply suitable protective equipment such as capacitors and lightning arresters.

3. There does not appear to be any functional relationship between either furnace size or primary voltage and the number and magnitude of transients on a times normal basis.

4. The magnitude of secondary transients suggests that they originate from current discontinuities in the secondary circuit.

5. This report does not cover internal transformer voltages.

6. Although this report is primarily a factual presentation of test data on voltage transients, some members of the committee thought it desirable to stress the use and adequate maintenance of a mechanically rugged circuit breaker especially selected for arc-furnace service.

Recommendations for Future Analysis and Study

The magnitude of furnace transients, both primary and secondary, appears to be very closely associated with the characteristics of the electric system, and it may prove worth while to investigate this relationship by future calculation and theoretical analysis. It is believed that sufficient power-system data have been tabulated along with the test data to permit such a study by an analysis group.

Wherever the point has been checked, the addition of high-voltage capacitors has been found to reduce both the number and magnitude of the transients recorded, and this fact may support the view that system characteristics are an important factor.

A New Carrier Relaying System

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IT has long been realized that the surest and most effective way to obtain simultaneous breaker operations at both ends of a transmission line, regardless of the location of a fault within the line section, is by use of some form of pilot channel relaying. Two forms of this type of protection have been developed and used very successfully for a number of years. One system is the familiar distance-type carrier relay system, and the other is the single-element differential pilot-wire system.

This paper describes a new one-to-three-cycle carrier relaying system which combines the simplicity of pilot-wire protection with the versatility of power-line carrier.

A comparison of the characteristics of the distance-type carrier and pilot-wire relaying systems gives the background and reveals the impelling motives for the development of this new system. The distance type of relaying requires a source of current and potential to determine the location of a fault. Backup protection is provided, and auxiliary elements are required to prevent tripping on an out-of-step condition. Consequently, the contact and circuit complication has been increased over that required for a basic carrier relaying system.

In the single-element pilot-wire system, which has been in use for a number of years, certain problems were solved which resulted in definite steps toward simplicity. The chief progress toward simplicity in this scheme was effected by the use of relays operating on symmetrical components of current. This obviated the necessity of using separate relays in each phase and reduced the relay requirements to one per terminal to handle all phase and ground faults. This same symmetrical-component device also reduced the number of pilot wires to two.

No potential source is required for this pilot-wire system, since the positive- and zero-sequence components of the fault current at each end of the protected lines are compared.[1] System out-of-step conditions do not tend to trip the relays and, therefore, do not require auxiliary elements to prevent tripping. The resistance of the pilot wire is one limiting condi-

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tion, however, for this relay. Furthermore, in some cases induction in the pilot wire and differences of ground potential cause undesirable effects.[5]

It is evident from the foregoing that a marked simplification in a carrier relaying system is possible by using the elements of the pilot-wire relay and substituting a power-line carrier channel for the pilot wire. A carrier relaying system of such a nature has been developed, and extensive tests on an artificial transmission line in the laboratory and on an actual line in the field have proved it to be dependable in operation.

Principle of Operation

Basically the relays determine whether a fault is inside a protected line section or external to it by comparing, over the carrier channel, the relative directions of the currents at the ends of the line section. This comparison takes place in the grid circuit of a vacuum tube connected as shown in Figure 1. The tube is normally biased to cutoff; that is, the bias voltage E_c is sufficient to block the flow of plate current when no other voltage is present in the grid circuit. Carrier is transmitted from both ends of the line on alternate half-cycles of the power frequency. A voltage proportional to the received carrier is introduced into the grid circuit of the vacuum tube in series with a single-phase voltage derived from the local line currents. The polarities of these two voltages are such that for an internal fault current flows through the vacuum-tube plate circuit on alternate half-cycles of the power frequency. A voltage is thus induced into the secondary winding of transformer TR which is sufficient to operate the relay element R and close the trip circuit. For an external fault, the phase of one of the voltages in the grid circuit reverses, and the flow of plate current is continuously blocked. Therefore, no voltage is induced in the transformer secondary winding, and the relay does not operate. This vacuum tube is appropriately called a "relay tube" because of its function, and it will be referred to as such hereinafter.

Complete System

Figure 2 shows a complete basic diagram of one terminal of the relaying system. The three-phase line currents energize the positive-plus-zero-sequence filter. The single-phase output of the sequence filter is connected to a fault detector and to the grids of two thyratrons $V1$ and $V2$. These thyratrons and the associated re-

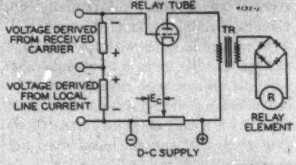


Figure 1. Relay tube circuit in which local and distant currents are compared

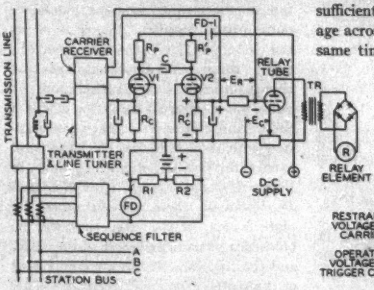
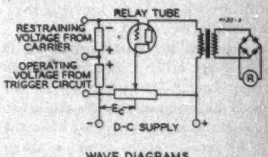


Figure 2 (left). Complete basic diagram of simplified carrier relaying system

sistors and capacitors comprise a trigger circuit which is operated by the filter output voltage. The fault detector is used to obtain an intermittent carrier scheme, so that the carrier channel is available for any auxiliary function such as communication or telemetering except during the time of a fault.[4] One contact on the fault detector (FD-1) starts carrier through the thyratron trigger circuit, and another contact (not shown) is used to interrupt any auxiliary function.

Upon the occurrence of a fault, the contact of the fault detector closes and applies positive direct voltage to the plate circuits of $V1$ and $V2$. When the grid of $V1$ becomes positive, as a result of the filter output voltage, it fires and its plate or anode current very rapidly rises to a steady-state value as determined by the supply voltage and the plate and cathode resistors (R_p and R_c) of the tube. On the next half-cycle, the grid of $V2$ becomes positive, and thyratron $V2$ fires. When this occurs, the charge on the capacitor C, connected between the plates of $V1$ and $V2$, makes the plate potential of $V1$ momentarily negative which extinguishes $V1$. Thus the wave form of plate current of either thyratron will be square half-cycles of fixed magnitude for any value or wave form of grid voltage, providing, of course, sufficient grid voltage is present to fire the thyratrons $V1$ and $V2$. The voltage drop across the cathode resistor R_c is used as the plate-supply voltage for the oscillator tube in the carrier transmitter. Applying this voltage to the plate of the oscillator causes the transmission of carrier on alternate half-cycles of the power frequency.

The voltage drop across the other cathode resistor R_c' of thyratron $V2$ is connected in the grid circuit of the relay tube in series with the d-c output of the carrier receiver (E_R) as shown. When $V2$ fires, the voltage drop across R_c' makes the grid of the relay tube positive. The d-c output of the carrier receiver is connected with the opposite polarity and is sufficient to cancel the effect of the voltage across R_c' if carrier is received at the same time that $V2$ is conducting. The



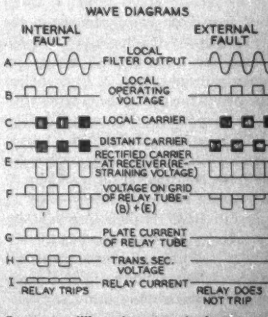


Figure 3. Wave diagrams of relaying quantities

remainder of the relay-tube circuit is the same as shown in Figure 1. The carrier transmitter and receiver are conventional carrier relaying units whose construction and principle of operation are well known.

Response to Faults

Figure 3 shows in detail how the circuits just described determine whether an internal or external fault exists. The relay-tube circuit is repeated at the top of Figure 3 for convenience. The "operating voltage from trigger circuit" is the voltage drop across R_c' of Figure 2. It is called operating voltage, as it makes the grid of the relay tube positive, causing the flow of relay-tube plate current. The

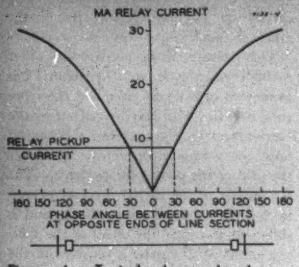

MA RELAY CURRENT
30
20
10
RELAY PICKUP CURRENT
180 150 120 90 60 30 0 30 60 90 120 150 180
PHASE ANGLE BETWEEN CURRENTS AT OPPOSITE ENDS OF LINE SECTION

Figure 4. Typical phase-angle–relay-current curve of system

"restraining voltage from carrier" is the d-c output of the carrier receiver (E_R) and is so named as it opposes the operating voltage and prevents the flow of plate current in the relay tube by applying negative potential to its grid.

To see how the quantities shown in Figure 3 are utilized, consider first an internal fault. The polarities of the sequence-filter output voltages at the two ends of the line are such that, when the fault detectors operate, carrier is transmitted from both line terminals on the same half-cycles (Figure 3, *C* and *D*). The received and rectified carrier restraining voltage (Figure 3, *E*) is applied to the grid of the relay tube in series with the operating voltage (Figure 3, *B*). The net voltage on the grid of the relay tube is the sum of these two voltages, and has the wave form indicated at *F* on Figure 3. The reference axis at *F* is the voltage E_x required to cut off the plate current of the relay tube. Consequently, when the net grid voltage is above this axis, plate current flows. For an internal fault, there is no rectified carrier voltage during the half-cycles that the grid of the relay tube is made positive by the operating voltage. As a result, plate current will flow in the relay tube, as shown at *G* in Figure 3. The half-cycle plate-current pulses flow through the primary winding of the transformer *TR*. The secondary voltage (Figure 3, *H*) is rectified to provide a steady relay operating force, and the direct voltage so obtained causes current to flow to operate the relay *R* (Figure 3, *I*).

During an external fault, when the fault detectors pick up, carrier is transmitted from the two ends of the line on alternate half-cycles, as shown at *C'* and *D'* in Figure 3. This change occurs because the current at one end of the line has reversed with respect to the current at the opposite end. If the current entering the line is in phase with the current leaving it, the rectified carrier at each receiver will provide a substantially continuous restraining voltage (Figure 3, *E'*). This voltage in series with the operating voltage (3, *B'*) gives a resultant value which is always more negative than the cutoff bias of the relay tube (Figure 3, *F'*). As a result, no plate current flows (Figure 3, *G'*), and the relay does not operate.

The phase position of the line currents theoretically may fall anywhere between the inphase position and the 180-degree out-of-phase position. Figure 4 shows the characteristics of the relay over this entire range. As the phase position changes from in phase (external fault) to out of phase (internal fault), the blocks of the distant carrier change in phase position with respect to the blocks of local carrier, the two extremes being shown in Figure 3, *C* and *D*, and Figure 3, *C'* and *D'*. Between these two extremes the plate current of the relay tube will be blocked over more and more of the cycle, and the rms value of the a-c component of the plate current will decrease. This will result in a decrease of the current in relay *R* as shown on the typical phase-angle relay-current relationship Figure 4. By adjusting the sensitivity, the relay *R* can be set to operate when the angle between the currents at the two ends of the line becomes any desired value, such as 30 degrees, as shown.

The preceding explanation is based on single-frequency operation of the carrier equipment. That is, the transmitters and receivers at both ends of the line are tuned to the same carrier frequency. It should be noted, however, from a comparison of Figure 3, *B* and *C*, that carrier is transmitted locally only on the half-cycles when there is no operating voltage present. Consequently, it is never necessary to receive the local carrier signal, since the relay-tube plate current always will be zero during these half-cycles. This means that two-frequency operation of the carrier transmitters and receivers is possible without complication, if it is desired to use some auxiliary function which requires a two-frequency channel. In two-frequency operation, the transmitter at one end of the line and the receiver at the opposite end are tuned to one carrier frequency, and the other transmitter and receiver are tuned to a different frequency. This permits simultaneous transmission and reception in both directions as would be needed for telemetering in one direction and load control in the opposite direction. When two-frequency operation is used, the line trap at a given station is tuned to the frequency transmitted from that station.

Figure 5. Type-HKB relay used in simplified carrier relaying system described in paper

Special Considerations

Although the settings of the fault detectors at both line terminals usually will be the same, there is the possibility of a distant external fault picking up the fault detector at only one end of the line. As blocking depends on receiving a signal from the opposite end of the line section, carrier must be started at both line terminals before operating voltage is applied to the relay tube at either end.

To do this, the thyratron which starts carrier is set more sensitively than the one which provides operating voltage to the relay tube. The carrier-controlling thyratron also is more sensitive than the fault detector and therefore always will fire whenever the fault detector picks up, but the thyratron which provides operating voltage is set less sensitively and therefore will not fire until the fault current reaches a value approximately 50 per cent above the fault-detector setting. Thus, if the fault current is just above the pickup value of the fault detector, it will pick up, and thyratron *V*1 (Figure 2) will fire and cause the transmission of a continuous carrier signal. The two thyratrons will not trigger back and forth until the fault current is high enough to fire *V*2. Then the system will operate in its normal way. The firing point of *V*2 need be enough above that of *V*1 to insure that the fault detectors at both ends of the line pick up and start carrier before operating voltage is applied to the grid of either relay tube. The difference in

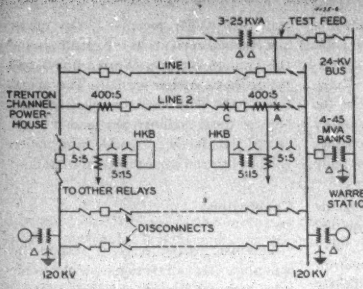


Figure 6 (left). Transmission-system conditions for staged tests

Figure 7 (right). Oscillogram of operation during internal fault

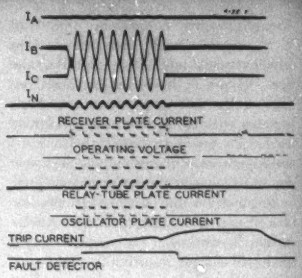
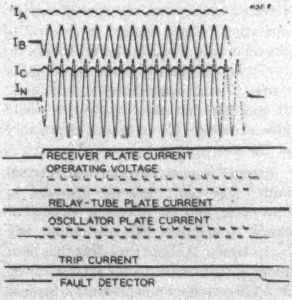


Figure 8 (below). Oscillogram of operation during external fault



settings of $V1$ and $V2$ can be accomplished easily by adjusting the resistor $R1$ in Figure 2 larger than $R2$ to obtain the proper voltage distribution. As the sequence-filter output voltage increases, more of it will be applied to the grid of $V1$ than to that of $V2$, thus allowing $V1$ to fire at a lower fault current than $V2$.

One of the fundamental requirements of the new current-comparison carrier system is that no dependence be placed upon the relative magnitudes of the fault currents at the two ends of the protected line section. In this respect the system operates somewhat differently from the pilot-wire relay in that it is not a ratio-differential scheme but operates only on the relative phase position of the currents at the two ends. The reason why magnitude comparison cannot be used is that to do so would entail the reception of a carrier signal through an internal fault. Also, the attenuation of a power line to carrier frequencies changes with weather and system switching conditions, resulting in the reception of a signal which varies in strength over a wide range. While some signal, no doubt, could be received through an internal fault, especially if high power were used, it seems fairly obvious that no dependence could be placed on the reception of a signal of the proper magnitude. In the present system, therefore, the circuits which control tripping and blocking are saturated at as low a current value as possible, and only the variation in phase position is utilized to discriminate between internal and external faults. Also, it is only necessary to receive a signal from the far end of a line section when blocking is required, that is, during a fault external to the protected section.

The carrier receiver saturates at a small value of received signal and provides sufficient restraining voltage to give a good margin of safety over the operating voltage over a very wide range of carrier attenuation. This is done to insure dependable blocking for external faults. It should be noted in Figure 3, C, D, and E, that the restraining voltage due to the reception of both the local and distant signals is no greater than for the reception of the distant signal alone (Figure 3, C', D', and E'). This is due to the saturation of the carrier receiver. As a result of saturating all the quantities involved, a single curve (Figure 4) suffices to show the relay-system characteristic over a wide range of fault currents.

On lines with a source of power at only one end, this system will block for an external fault beyond the line terminal having no source of power. However, for an internal fault, only the end having a source of power will trip. This operation is the same as for a standard distance-type carrier relaying system.

The application of this relaying system to three-terminal lines has been considered, and there appears to be no fundamental reason why it will not operate satisfactorily.[6] However, to date no actual tests on a three-terminal line have been made.

There is a theoretical condition where the use of the positive-plus-zero sequence filter may result in incorrect operation. This occurs on an internal B-C-to ground fault when the positive-sequence current all comes from one end of the line and the zero-sequence current all comes from the opposite end. In addition the magnitudes must be exactly right, and the phase angle of the positive- and zero-sequence system impedances must be equal. This same condition exists for the pilot-wire relay which uses the same type of network filter, but in no installation has this exact condition ever been encountered. If it is a condition which must be satisfied, the use of positive sequence alone is a solution.

The Equipment

The relay proper contains the positive-plus-zero sequence filter, the operating element, and the fault detector. Figure 5 is a picture of the relay in a case equipped with switches to facilitate testing. The trigger circuit, relay tube, and associated components are mounted on a 19-inch-wide panel for relay rack mounting in the same cabinet as the carrier transmitter and receiver. Provision is made to check the operation of the circuits without disturbing the installation.

Field Tests

In order to obtain field experience under typical service conditions, the first installation of this carrier relaying system was made in April 1944 on a 120-kv transmission line of The Detroit Edison Company's system. Before being installed in the field, the equipment was set up completely by the company in its laboratory for a preliminary trial. A miniature transmission line, which could be fed independently from either end, was connected to the relays through current transformers, and all types of fault conditions were simulated. These preliminary tests did not disclose any incorrect relay operations during a large number and variety of applied faults. The tests also permitted a very complete study of the effects of all adjustments on the equipment.

After this thorough trial in the laboratory, the equipment was installed on the Trenton Channel–Warren line 2 (see Figure 6) which is one of four parallel circuits feeding the Warren station from the

Trenton Channel powerhouse. On April 2, a series of staged tests was run, in which artificial faults were applied to the line. Figure 6 shows the pertinent details of the line and bus arrangement, together with the special test connections used. To minimize the disturbance to the system, two circuits on the same tower line were connected in series, as indicated on the diagram, and energized at only one fifth of normal voltage from the Warren station 24-kv bus. To compensate for the lower current resulting from this circuit arrangement and to obtain values more representative of actual faults, the secondary current was stepped up three times through a set of auxiliary current transformers before feeding into the relay. The 24-kv system is solidly grounded in the same way as the 120-kv system. The a-c source was connected to the line 1, and the faults were applied to line 2 at the Warren station terminal under three different test conditions. In the first condition, the fault was applied at point *A* (Figure 6) just external to the protected zone. For the second condition, the fault was applied at the same point, but at Warren station the polarity of the sequence-filter output was reversed to simulate an internal fault with a source of power at both ends of the line. For the third condition, the fault was applied at point *C* to simulate an internal fault fed from only one end of the line.

Ten tests were made under each of the conditions outlined, including a solid three-phase fault and all combinations of line-to-line, double-line-to-line-to-ground, and single-line-to-ground faults. In all cases, the test condition was set up with the 120-kv lines de-energized and then the 24-kv breaker was closed to initiate the fault current. In every case, the relays operated correctly. No tripping occurred on any of the external faults, whereas all internal faults were cleared promptly by the action of the proper circuit breakers.

Oscillograms were taken at Warren station of every test and showed essentially consistent and positive operation of all components of the relaying system. The test control sequence was such that oscillographic records of the beginning and the end of the fault-current flow were recorded whether the fault was cleared by the line breaker or by the test feed breaker. This was done so as to include on the oscillograms the effect of switching transients.

The average relaying time was 2.5 cycles with the slowest operation a cycle longer which was probably due to the random initiation of the fault in terms of the 60-cycle wave. This can result in a variation of about one cycle in the point at which the trigger circuit applies operating voltage to the grid of the relay tube. For these tests, the plate circuits of the thyratrons *V*1 and *V*2 were continuously energized, and the fault-detector contact was in the plate-supply lead to the relay tube.

Typical oscillograms taken during the staged tests are shown in Figures 7 and 8. The quantities recorded include relay current in the three phases and neutral, detector plate current which indicates received carrier and restraining voltage, operating voltage applied to the grid of the relay tube, the plate current of the relay tube, oscillator plate current, trip current, and fault-detector operation. It was felt that these quantities would give a complete record of the performance of the new system.

Figure 7 is an oscillogram of an internal fault. The fault detector operated in 0.75 cycle, and the operating element *R* closed to complete the trip circuit two cycles later. A slight time delay has been added intentionally to the relay element *R*. This was done as a precaution against operation on a single pulse of energy caused by a transient during the clearing of an external fault. The tests indicate that the time delay selected was more than enough. Additional tests in the laboratory are being made to determine the amount of time delay, if any, which will be required. Figure 8, which is an oscillogram of an external fault, indicates that the time delay is unnecessary. Reference to the trace of relay-tube plate current in Figure 8 shows that it remained zero during the entire time of fault. The external fault was cleared by automatically opening the 24-kv breaker approximately 18 cycles after it closed. The wave form of the quantities recorded on the two oscillograms is in good agreement with the theoretical values shown in Figure 3. The carrier receiver was adjusted for a high sensitivity to obtain the maximum effect of any transient which might affect the received carrier signal.

The equipment was put into service immediately after the tests, and has performed according to expectations to the date of this writing. Special records on the operation of this equipment are being kept. Indicators and counters provide records of the operation of the fault-detector and the tripping relay. Warren station has an automatic oscillograph in service which records three-phase voltage and neutral current on the 24-kv system. Another has been added for this trial installation which records 120-kv phase and residual currents in the generator and the Trenton Channel–Warren line 2, and the received carrier signal. The operation of the fault-detector relay initiates both of these oscillographs, and it is expected that further valuable information will be obtained from this combination.

Conclusions

This new carrier relaying system, by combining the advantages of electronic tubes and symmetrical-component filters, results in a marked simplification over previous carrier relaying systems. The number of relays required for complete phase and ground protection has been reduced to one per terminal, and the number of moving elements in the relay has been reduced to two.

The system operates on current only, eliminating the need of a source of potential and the attendant requirement of minimum voltage operation. It will not trip during system swings or out-of-step conditions. It is particularly well adapted to installation on circuits where existing relays would provide satisfactory backup protection to a carrier system. For this reason, lower-voltage circuits from 66-kv down appear to present a large number of possible applications for the new relay system.

The use of a fault detector retains the feature of an intermittent carrier system and permits the use of the relaying carrier channel for other services.

The system compares phase positions of current and therefore can be made very sensitive. It is easily applied, and the saturation characteristics make it practically independent of fault-current magnitudes.

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Current-Transformer Output and Application Charts

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Synopsis: The performance of a multiratio current transformer is most simply represented as a function among the admittance vector locus of the core for one turn, the secondary-turn number N, and the secondary impedance Z. If the ratio of N^2/Z is used as a variable, extremely simple application charts for ratio correction factor in relation to primary currents result. The ratio N^2/Z furthermore is basic in the matching of transformers and burdens for maximum volt-ampere output at given primary current. Methods for computing the optimum volt-ampere output are given, and a chart is derived from which all data for a correct matching can be obtained at once. The usefulness of these methods is explained in connection with various examples such as applied to relaying circuits commonly used.

IN recent years the theory of operating of multiratio bushing-type current transformers has been given extended study resulting in a simplification of the application curves.[1,2] There is still lacking, however, a single chart from which the ratio correction factor for any value of primary current, any turn number, any secondary burden, and burden power factor can be read directly. In this paper a study is made to determine the feasibility of such a chart.

To date, there is very little information available on the secondary-output variation with relation to primary current, turn numbers, and burden. In many instances the secondary volt-ampere output is the quantity determining the operation of connected apparatus, such as instruments and relays. It therefore appears that benefits would be derived from a formulation of the output characteristics, particularly in the field of low primary currents. Of particular value would be the development of a volt-ampere-output application curve which would enable the relay engineer to determine quickly the optimum performance.

Standard Application Curves

In recent years numerous efforts have been made to simplify the representation of errors in multiratio relaying-type current transformers. A particularly simple graphical solution results for the ratio correction factor and phase-angle error when the admittance-vector locus of the steel core is used.[1] The complex ratio can be represented as a function of the number of secondary turns, the secondary burden and the admittance vector for one turn.

If one designates

N = number of secondary turns
Z = total secondary burden
Y_1 = admittance vector for one turn
$R(1/1)$ = one-to-one ratio

the following relation exists:

$$-R(1/1) = \frac{\frac{N^2}{Z} + Y_1}{\frac{N^2}{Z}}$$

resulting in the transformer chart shown in Figure 1 for the case of a typical 23-kv specimen. All the following charts will be based on this 23-kv specimen. In most relaying applications knowledge of the phase angle is not required. The small amount of drafting work necessary in conjunction with Figure 1 can be avoided by plotting curves representing various N^2/Z values in a co-ordinate system with ratio correction factor as ordinate and primary current as abscissa.

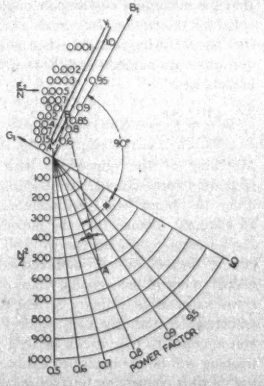

Figure 1. Chart for calculation of ratio and phase angle for any number of secondary turns N, any total burden Z at any power factor, and any desired secondary current I_s, provided $N^2/Z \leq 1{,}000$

Instructions:

1. Compute volts per turn I_sZ/N and mark point on locus Y_1, corresponding to this value as B
2. Compute N^2/Z and mark corresponding point A at proper power factor
3. Phase angle θ = angle OAB
   True ratio $R_N = I_1/I_s = N \times AB/AO$

N = Number of secondary turns
Z = Total secondary impedance

Figure 2 represents a practical chart giving the required information without necessitating drafting and with the least amount of computations. As has been pointed out in a recent paper,[2] for most transformers the ratio error is not affected greatly by changes in the power factor of the burden. The curve therefore applies for any burden power factor encountered in practice. The use of the chart shall be explained in conjunction with an example:

Assumed total burden = 4.0 ohms (at 50 per cent power factor)
Transformer ratio = 250/5 = 50/1

What is the ratio correction factor for a primary current of 150 amperes?

Calculate

1. $\frac{N^2}{Z} = \frac{50^2}{4} = 625$

2. $I_1 \frac{Z}{N^2} = \frac{150}{625} = 0.24$

Select this latter abscissa on the chart, point A, and follow vertically to the curve corresponding to $N^2/Z = 625$. If there is no curve drawn for this value, interpolate between two curves including this value, giving point B. The ordinate of point B corresponds to the ratio correction factor (RCF), the value of which can be read on the ordinate axis, point C, giving RCF = 1.11. This chart permits the quick determination of the RCF of a specific transformer for any secondary-turn number, any secondary burden of any usual power factor and at any primary current. It has the advantage of not being limited to the specific burdens usually referred to on similar charts. This seems to be an important feature since burdens encountered in practice never or only accidentally correspond to these specific burdens.

Figure 2, together with the admittance-vector-locus chart shown in Figure 3, appears to satisfy the American Standard C57.1—4.033, covering current-trans-

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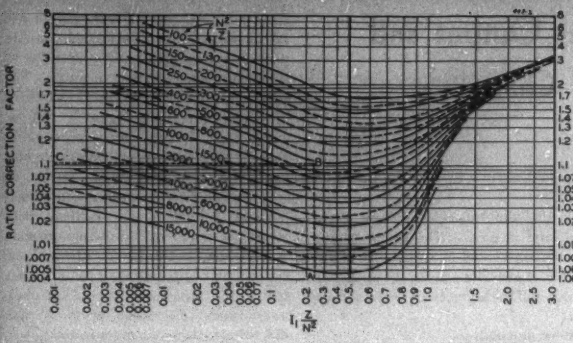

former application data completely and in the simplest and still most general form. A chart similar to Figure 2 can be prepared for the representation of the phase-angle errors. Such a chart, however, is sensitive to power-factor changes in the burden and therefore is limited to one specific power factor.

Figure 2. Chart giving ratio-correction factor for any number of secondary turns N and any total secondary impedance Z at power factors between 50 and 100 per cent and for any primary current

Internal $R = 0.0022N$ ohm
Internal X considered negligible

Secondary Volt-Ampere Output

It is the prime purpose of a current transformer to provide an appropriate supply of secondary power for the operation of various devices, such as meters, relays, and trip coils. These devices require a definite amount of power to perform the desired operation. Difficulties are encountered in many cases where operation is required at very low primary current. It is known that for each multiratio transformer there appears to be a definite ratio giving best performance under given primary current and load conditions. In the following it will be shown, that the optimum performance of any multiratio transformer can be determined from a turn-impedance matching chart requiring but a few simple computations. Since this chart is based on an analysis of the secondary volt-ampere output in relation to primary current, turn number, and secondary burden, these factors shall be investigated in detail. It will be seen that the admittance-vector locus offers a simple means of obtaining the desired data.

Variation in Volt-Ampere Output With Varying Secondary-Turn Number, Constant Secondary Impedance, and Constant Primary Current

Figure 4 shows the variation in secondary volt-ampere output for 500-ampere primary current and two secondary burdens of 3.4 ohms and 13.6 ohms, in relation to the secondary-turn number. It can be seen that pronounced maxima exist at 40 and 80 turns respectively. For the 3.4-ohm burden the output at 20 turns is only about one-third the maximum output of 325 volt-amperes occurring at 40 turns. It can be noted further that the maximum volt-ampere output is equal for the two burdens considered and that the following relation exists between optimum turn numbers and the respective impedances:

$$\frac{N^2}{Z} = \frac{40^2}{3.4} = \frac{80^2}{13.6} = 471 = \text{constant}$$

Matching of the impedance with the secondary-turn number is essential in order to obtain best performance. As an example, assume that the impedance $Z = 3.4$ ohms represents the trip coil of a circuit breaker which is directly connected to one of the secondary taps of the transformer whose primary current is 500 amperes. If the trip coil requires 300 volt-amperes to trip, it can be seen that tripping will be accomplished easily with the 40-turn connection but is impossible with any of the other standard connections of the secondary winding.

Variation in Volt-Ampere Output With Varying Secondary Impedance, Constant Turn Number, and Constant Primary Current

Figure 5 shows the variations in volt-ampere output for 500-ampere primary current, for various fixed secondary-turn numbers and varying burden impedance. The maximum volt-ampere output again amounts to 325 volt-amperes. The output is very sensitive to changes in magnitude of the burden impedance but is only little affected by changes in power factor as shown in Figure 5. The optimum performance occurs at the same N^2/Z value of 471 as found in Figure 4. From Figures 4 and 5 it follows that for a given primary current there exists a definite volt-ampere-output maximum. It can be seen also that independent of the secondary-turn number N the maximum occurs at a definite flux density of the core corresponding to $E_s/N = 0.83$ volt per turn in case of 500 amperes primary current.

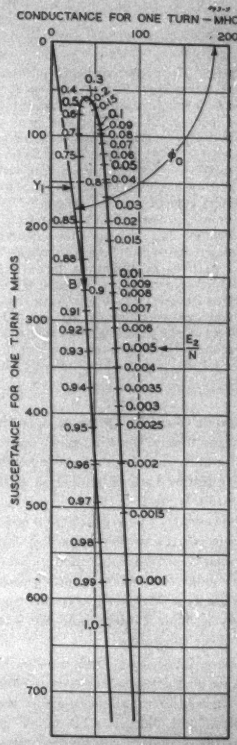

Figure 3. Admittance-vector locus Y_1 in mhos for one turn as a function of volts per turn

Determination of exciting current:

1. Determine volts per turn $I_2 Z/N$ giving point B, $Y_1 = OB$ and ϕ_0
2. $Y_N = Y_1/N^2$
3. $I_t = Y_N E_s$

Internal reactance considered negligible
Internal resistance, $R = 0.0022N$

Variation in Volt-Ampere Output With Varying Primary Current

Increased volt-ampere output requires increased primary current. Figure 6 represents tests on 80 turns with varying primary current and varying secondary impedance. At 1,000 amperes the maximum equals 710 volt-amperes; at 700 amperes 480 volt-amperes; at 500 amperes 325 volt-amperes, and at 300 amperes 175 volt-amperes.

For various primary currents and constant number of turns the maxima do not occur at the same secondary-burden impedances and hence not at the same value of N^2/Z. Therefore, if a transformer has been matched for optimum volt-ampere output at a specific primary current, the secondary impedance and turn numbers must be rematched for another primary current to produce maximum output. The curves shown in Figures 4, 5, and 6 are too involved for use as practical application curves. Figure 7 shows a curve A which relates the primary current with the burden impedance Z and the turn number N, in particular N^2/Z, at which the output maximum occurs. Curve B designates the maximum volt-ampere-output corresponding to various primary-current values. The use of this chart will be explained by means of a specific example.

A relay having a burden of six ohms is set to operate at five amperes. What is the minimum primary current value at which tripping takes place and what is the corresponding optimum turn number?

The secondary volt-amperes at tripping are equal to $5^2 \times 6 = 150$ volt-amperes. From curve B, Figure 7, the corresponding minimum primary current amounts to 275 amperes. If we refer to curve A, the corresponding N^2/Z value amounts to 260. Since Z is equal to six ohms

$N^2 = 6 \times 260 = 1{,}560$ giving

$N = \sqrt{1{,}560} = 39.5$ turns

The closest turn number available on standard taps is 40 turns. The relay should be connected to this tap; if the relay were connected to a different tap of the transformer, tripping would take place only at a higher primary current. It is apparent that impedance matching is essential in order to procure best performance.

Graphical Determination of Volt-Ampere Output From Admittance-Vector Locus

The secondary output can be determined readily from the admittance-vector locus, for one turn as will be explained in the following.

Figure 8a shows a graphical representation of the primary, secondary, and exciting ampere-turn relation of a transformer with equal number of primary and secondary turns N. For the case of one primary turn and N secondary turns the single-turn primary current can be obtained from the relation $I_1' = NI_1$.

The current diagram 8b is obtained from the ampere-turn diagram by dividing the vectors in diagram 8a by the turn number N. As a first step it will be indicated how the volt-ampere output can be constructed from this current diagram. This method requires an exciting-current curve in polar form.

For a fixed value of primary current the distance BC in Figure 8b remains constant, whereas $OB = I_e$ and $OC = I_2$ vary with the secondary impedance, respectively with corresponding variation in volts per turn. With open circuited secondary the primary current is equal to the exciting current $I_1 = I_{e0} = OA$. The procedure of obtaining the volt-ampere output for constant primary current is therefore to assume a secondary-voltage value E_2, determine the exciting current giving point B and find the intersection of the circle with center at B and radius I_1 with the line OC corresponding to the power-factor phase angle of the secondary burden, giving $OC = I_2$ and the output $= I_2 E_2$.

However if the vectors in Figure 8b are multiplied by N^2/E_2, the admittance diagram 8c is obtained. Since the admittance-vector locus is available (Figure 3), it is advantageous to use it in the determination of the volt-ampere output. Whereas in Figure 8b, distance BC is constant, in Figure 8c it varies with the secondary volts per turn value E_2/N.

The secondary volt-ampere output for a constant primary current $I_1' = NI_1$ and a specific value of E_2/N represented by point B can be obtained as follows:

1. Calculate $\dfrac{I_1'}{E_2/N}$

2. Intersect the circle with center B and radius $I_1'/(E_2/N)$ with the power-factor line OD, producing point C.

3. The volt-ampere output at point B is equal to $E_2^2/Z = (E_2/N)^2 N/Z$ and is obtained by scaling OC and multiplying its value by $(E_2/N)^2$ of point B. This output is plotted most conveniently in an orthogonal co-ordinate system with OD as abscissa, as indicated in Figure 8c.

Figure 8c brings out the important fact that the volt-ampere output is not primarily a function of Z or N, but of the ratio N^2/Z. This is the basic variable in volt-ampere-output problems as well, and it is for this reason that the impedance matching curves (Figure 7) become simple.

Mathematical Determination of Volt-Ampere Output

Without loss in generality, the volt-ampere output can be computed by assuming a transformer having one primary and one secondary turn. In the equivalent diagram, it can be represented as shown in Figure 9 where Z_T represents the impedance of the transformer and Z_B the secondary-burden impedance. Depending on the value of Z_B, a larger or

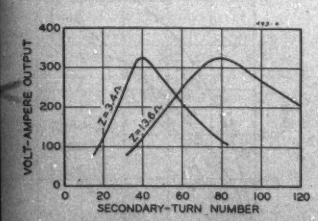

Figure 4. Variation in volt-ampere output with varying secondary-turn number, fixed secondary impedances, and constant primary current

$I_1 = 500$ amperes
Burden power factor = 0.5

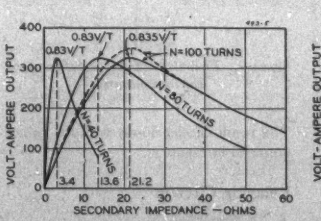

Figure 5. Variation in volt-ampere output with varying secondary impedance, fixed turn numbers, and constant primary current

$I_1 = 500$ amperes
——50 per cent power factor
– – –90 per cent power factor

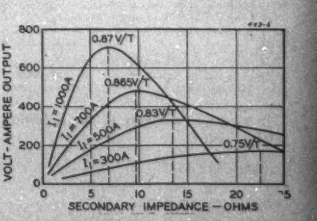

Figure 6. Variation in volt-ampere output with fixed primary currents, varying secondary impedance, and constant secondary-turn number

50 per cent power factor
$N = 80$ turns

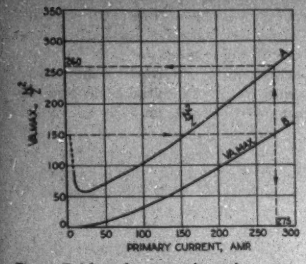

Figure 7. Impedance matching chart giving maximum volt-ampere output and corresponding N^2/Z for a given primary current

smaller portion of the constant total current I_1 is diverted through the secondary winding. Z_T is equal to $1/Y_1$ and is obtained from Y_1 by complex inversion, resulting in Figure 10. In case of a highly reactive burden Z_B, a close approximation is obtained by neglecting the resistance in Z_T and Z_B. This simplification is similar to that previously made in the case of inphase addition of currents.

It has been shown further that the susceptance component B_1 of Y_1 is proportional to the eighth power of the secondary voltage for high flux densities, and proportional to $E^{-0.4}$ for very low flux densities.[1]

An example covering the high flux-density range will be computed in the following, the primary current being assumed 500 amperes: With the transformer open-circuited, the entire primary current is used to magnetize the core, resulting in

$$I_1 = Y_{1.0}E_{2.0} \text{ for } N = 1$$

Reference to Figure 3 proPuces $Y_{10} = 514$ mhos, $E_{2.0} = 0.973$ volt. These values can be established by a few trials.

Y_1 for any secondary voltage E can therefore be expressed as

$$Y_1 = 514\left(\frac{E}{0.973}\right)^8$$

and

$$Z_T = \frac{1}{Y_1} = \frac{1}{640E^8}$$

If we refer to Figure 9, the following relations exist:

$$(500 - I_2)Z_T = E$$

$$(500 - I_2)\frac{1}{640E^8} = E$$

Hence

$$I_2 = 500 - 640E^9$$

and

$$VA = I_2E = 500E - 640E^{10}$$

which derivative with regards to E is to be zero for maximum volt-ampere output.

This results in

$$E_m = \sqrt[9]{\frac{500}{6{,}400}} = 0.754 \text{ volt}$$

Hence

$I_2 = 450$ amperes

and the maximum output $= 339\,VA$

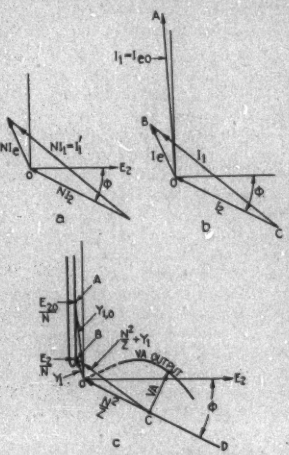

Figure 8. Graphical representation of relations between primary, secondary, and exciting ampere turns, currents, and admittances

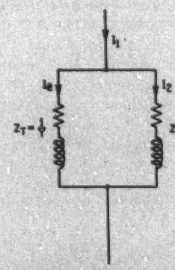

Figure 9. Equivalent circuit for bushing-type current transformer

This result checks closely with the values obtained in Figure 6.

Relaying Circuits

In many of the most common relaying circuits there is usually a large safety factor between the minimum amperes required to actuate the relay and the actual short-circuit current. In these cases little attention has to be paid to impedance matching in order to produce maximum volt-ampere output. In special cases, however, where the short-circuit current is low, where part of the secondary current of the transformer of the short-circuited phase is by-passed through idle transformers, and finally where impedances of relays are high or vary within great limits, a correct matching of the impedances becomes important.

In previous example it has been shown how the combination of a single transformer with a relay can be tuned to produce tripping at minimum primary current. The method outlined determines directly the optimum turn number for a given relay impedance by use of Figure 7. The method can be applied directly for a symmetrical three-phase short-circuit in conjunction with three-phase relays and one ground relay in accordance with Figure 11a. In case of single-phase-to-ground and phase-to-phase faults the method has to be modified because of the current by-passed in the idle transformers of the normal phases. For approximation calculations some simplifying assumptions can be made. The load current in the two normal phases will be neglected, and, whenever permissible, inphase addition of currents shall be applied. Small impedances also can be neglected when in series with large ones. Because of the nonlinearity of the circuits caused by the variation in the impedances in the by-passed transformer as indicated in Figure 10, the optimum performance has to be determined by a step-by-step method. Since no general rules applying to all the numerous relaying circuits can be set up, the application of the methods shall be given in conjunction with a specific example.

In the circuit shown in Figure 11a a

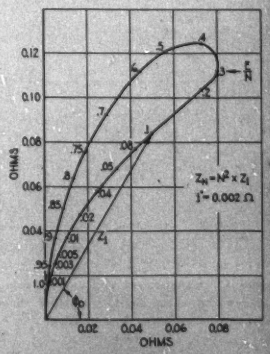

Figure 10. Impedance-vector locus Z_1 for one turn as a function of volts per turn

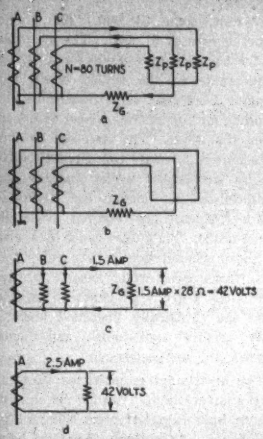

Figure 11. Relaying circuit and simplified representation

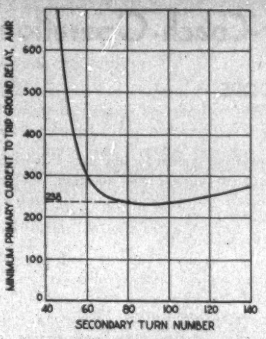

Figure 12. Optimum number of turns for relaying circuit of Figure 11

combination of ground relays has an impedance of 28 ohms (700 volt-amperes at five amperes) at 60 per cent power factor. The ground relays are actuated at 1.5 amperes.

The phase relays have an impedance of 0.2 ohm (five volt-amperes at five amperes) and 70 per cent power factor. A single-phase-to-ground fault is assumed in phase *A*.

The problem consists in determining:

1. The minimum phase-to-ground current in phase *A* necessary to trip the ground relays.

2. The corresponding optimum secondary-turn number *N* of the current transformers.

In order to calculate the current by-passed by the idle transformers *B* and *C*, the small impedance of the phase relays can be neglected, and the circuit can be simplified according to Figure 11b. Since no rigorous solution is possible, the minimum primary current (which is just necessary to trip the ground relay) corresponding to several transformer ratios has to be determined, the results of which have been plotted in Figure 12. From these values the optimum turn number can be determined. As a first attempt the 400/5 ratio is selected corresponding to 80 turns. As a first step the currents by-passed through the secondary circuits *B* and *C* have to be determined. The admittance of the current transformers *B* and *C* can be obtained from Figure 3. If we refer to the simplified Figure 11c and recall that the ground relay trips at 1.5 amperes, the corresponding volts per turn are $42/80 = 0.525$. The admittance Y_1 is 77 mhos for one single turn. For 80 turns

$$Y_{80} = \frac{Y_1}{80^2} = \frac{77}{6{,}400} = 0.012 \text{ mho}$$

The circuit can be simplified further by combining the impedance of the secondary windings *B* and *C* with that of the ground relay. Since the power factors of relays and current transformers are not very different, the resultant admittance can be obtained by numerical addition.

$$Y = Y_B + Y_C + Y_{\text{relays}} = 2 \times 0.012 + 0.0357 = 0.0597 \text{ mho}$$

corresponding to a resulting impedance of 16.8 ohms. The total secondary current necessary to drive 1.5 amperes through the circuit is therefore

$$I_2 = 42/16.8 = 2.50 \text{ amperes.}$$

The problem now resolves itself to determine the primary current necessary to produce 2.50 amperes across a secondary burden of 16.8 ohms at 60 per cent power factor (see Figure 11d). This can be done by means of Figure 1.

The volts per turn are $\frac{42}{80} = 0.525$

$$\frac{N^2}{Z} = \frac{6{,}400}{16.8} = 381$$

$$R(1/1) = \frac{AB}{AO} = 1.19$$

$$R_{80} = I_1/I_2 = 80 \times 1.19 = 95.3$$

Therefore

$$I_1 = 95.3 \times 2.50 = 238 \text{ amperes}$$

If 80 turns are used, tripping can be accomplished for a relay current of 1.5 amperes with a primary current of 238 amperes. By repeating the calculations for other numbers of turns, a curve as shown in Figure 12 is obtained. From this figure it can be seen that the optimum performance occurs for $N = 90$ turns.

Conclusions

A simple application chart from which the ratio correction factor can be determined for any value of primary current, any number of secondary turns, and any secondary burden of practical power factor has been developed.

The secondary volt-ampere output of a current transformer at a given primary current varies with the secondary-turn number and secondary burden. In order to obtain maximum volt-amperes at a given primary current, matching of the secondary impedance and turns is required. A volt-ampere-output application curve has been developed which is readily applicable to numerous relaying problems.

References

1. Current-Transformer Performance Based on Admittance-Vector Locus, A. C. Schwager. AIEE Transactions, volume 61, 1942, January section, pages 26–30.

2. Bushing-Type Current-Transformer Characteristics, S. D. Moreton. AIEE Transactions, volume 62, 1943, September section, pages 581–5.

Economics of Trolley-Coach Operation

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MEMBER AIEE

Synopsis: The trolley coach is one of the newer vehicles used in urban transportation. In 1943 trolley coaches carried 8.7 per cent of all passengers on the transit lines of all United States cities having a population between 50,000 and 1,000,000, although trolley coaches are only 6.6 per cent of the vehicles. This paper points out the features of trolley-coach operation which fit it for a wide variety of service conditions. Results of trolley-coach operation in increasing gross revenues are given. The various developments which have contributed to low transportation expense are outlined. Comparisons of trolley-coach, streetcar, and motorbus operating expenses are included. Further progress in trolley-coach design, which can be expected to follow the war, will enhance the trolley coach's economic position.

SINCE the introduction of the modern trolley coach in 1928, it has demonstrated in almost every installation its ability to increase revenues and to operate at very low cost. The investment cost for trolley-coach service is low, and the quality of that service ranks very high compared to other transportation media. The vehicle itself and the materials used in the distribution system have been improved continually with resultant improvement in the financial showing. Further progress is under way.

As a result of the success of early installations, there are 3,500 trolley coaches in service in the United States and Canada. The number has been reached in spite of the years of depression and war, both of which have retarded the growth.

In the broad field of urban transportation there is room for many types of public conveyances; rapid-transit trains, streetcars, trolley coaches, motorbusses, and taxicabs. Rapid-transit elevated or subway service is limited to a few large cities, and taxicabs furnish a distinct type of service at a much higher price; therefore both will be omitted from further discussion. But most transit companies, in cities of 100,000 population up, are faced with the possible use of the three remaining types of vehicles. In order to develop the most useful transportation system for any city, it is necessary to answer the question, "Which vehicle or combination of vehicles will afford the best service to the public at a reasonable cost?"

The problem is almost always complicated by the presence of some form of public transportation that is inadequate or otherwise unsuitable. Sometimes it is a streetcar system whose only excuse for existence was the hope of its promoter that he might make an honest dollar. Sometimes it is a motorbus system which grew from unemployment and easy credit in a community which now would be better and more economically served by trolley coach or streetcar.

Although the transportation engineer cannot hope to find virgin territory where each type of vehicle can be fitted into its correct economic niche, the factors determining the selection of the proper vehicle should be recognized. Once the right perspective is obtained, the economic chaos which characterizes too many of our activities can be avoided. Investment, earning power, and cost of operation are the three important factors in determining the correct application.

Investment

The first consideration is the initial cost of an installation. It can be assumed that for equal standards of convenience and excellence shops, car houses, garages, and similar items will be about the same, regardless of the type of vehicle. Of course, the detail arrangements differ, and each form of vehicle requires a maintenance facility or practice peculiar to itself: such as tracks for the streetcar, double overhead wires for the trolley coach, and fueling provisions for the motorbus. Likewise some feature which keeps down the first cost may entail considerable differences in day-to-day expenditures for the several forms of vehicle. For example, with outdoor storage in cold climates electric vehicles may require preheating in varying amounts proportional to their size, and motorbusses need engine idling to prevent freezing and insure starting in the morning. Such things must be evaluated in determining the initial investment for maintenance facilities.

The modern streetcar has the highest first cost, some $18,000. The trolley coach is next at $13,000. The motorbus is the cheapest at $12,000 for a vehicle comparable to the trolley coach and ranging from that value downward, depending on how far one wishes to depart from that level. The streetcar has approximately 58 seats compared to 40 to 44 for the largest trolley coaches and motorbusses in common use; therefore fewer streetcars are required to handle equal traffic. The trolley coach is capable of higher schedule speeds than the motorbus; hence fewer trolley coaches are required for a given frequency of service. Also the electrically propelled vehicles have greater availability, and hence fewer spares are necessary.

The investment required for streetcar tracks is very high, $100,000 per mile of double track in paved street being a normal figure. As a result there has been little completely new track built in many years. When new track is required on a route, the advisability of replacing it or substituting some form of rubber-tired service must be studied. The trolley coach requires overhead lines which may cost from $7,000 to $20,000 per route-mile (four wires) depending on the conditions and the degree of permanence desired. The routing of trolley-coach lines warrants the most serious study. Not only is it wise to analyze shifts in population and travel habits to forecast their trends, but it is doubly desirable to lay out routes with as few crossings and turnouts as possible. Not only does complicated overhead greatly increase the first cost, but it slows down operation and increases maintenance cost.

However, first cost does not tell the whole story. It is apparent that the operating expenses of streetcars must be very much lower than those of motorbusses to offset their greater fixed charges. The fixed charges of the trolley coach obviously fall between the two, being materially less than those of the streetcar with its tracks, but still somewhat greater than those of the motorbus which uses no overhead. On the other hand, the operating expense of the trolley coach is so low that there is a very wide field where its total annual costs are lower than those of either streetcar or motorbus.

Gross Revenue

One of the features in which the trolley coach excels is its ability to attract and retain new patronage. The reasons for this passenger appeal are evident. The trolley coach is cushioned on rubber tires. It is not tied to rails like the streetcar,

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and therefore it is not subject to the annoying delays caused by broken-down or improperly parked automobiles and trucks. It loads at the curb. On the other hand it affords a higher type of transportation service than the motorbus. Its light and heat are obtained from central-station power; hence, both are ample. Adequate ventilation is provided. The trolley coach is free from the odors of hot oil and exhaust gases. Its accelerating rate is high, but there are no jerks due to interruption of torque during gear shifting as on motorbusses. Electric and air braking combine to give maximum safety and reliability The trolley coach

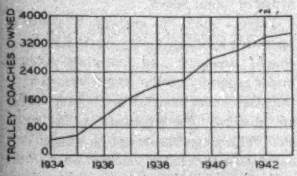

Figure 1. Ten-year record of trolley coaches owned in the United States

is the quietest public transportation vehicle.

The result of these superior characteristics is increased patronage. In one West Coast city the number of passengers on one route increased 15 per cent and on another 20 per cent when trolley coaches were substituted for streetcars. In an industrial city in Ohio where several lines were converted from motorbus and streetcar operation to trolley coaches, the revenue per vehicle-mile increased 20 per cent, and operating costs per vehicle-mile decreased 14 per cent. Gross revenue on one line in a large eastern city increased 47 per cent, although the system earnings during the same period decreased. On another line in the same city the increase in gross revenue was 21 per cent. In one southern city a new trolley-coach installation had a gross revenue increase of 47 per cent compared to an increase of 10 per cent on representative rail lines. In one eastern city 18 rail lines were converted to trolley-coach operation over a ten-year period. In every case patronage and revenue were increased.

Operating Expenses

Not only are trolley coaches able to increase gross revenues, but they are very economical in operation. Trolley coaches have been built in sizes seating 30 to 56 passengers, but most coaches have been of 40- to 44-passenger capacity. The discussion of operating expenses will be limited to that size.

Way and Structures

The maintenance of way and structures is now approximately 0.8 cent per coach-mile, compared to two to four times that amount per street-car-mile and 0.1 to 0.3 cent per bus-mile. The principal expenditure is for overhead lines, and great progress has been made in line construction as well as in current collectors. In the line material all parts attached to span or guy wires such as frogs and crossings are substantial castings to which are bolted renewable runners. These wearing parts can be renewed easily and quickly without disturbing the original construction. High-speed rigid curve segments with continuous wire underrun greatly reduce the complexity of the system of span and guy wires. These devices result in lower maintenance.

Another source of maintenance expense has been the gouging of the trolley wire adjacent to "special work" by the collectors. Proper design of frogs and crossings to avoid tilting of the collector not only reduces wire maintenance but also permits operation at higher speed.

The earlier trolley coaches used wheel trolleys similar to those used on streetcars, except that swivel harps allowed the coach to operate at either side of the overhead wires within the range of the trolley poles. The wheel trolleys caused considerable arcing and resultant short life of wire. They were noisy, and even with high contact pressure dewirements were too frequent. Wheel trolleys were soon superseded by bronze or steel shoes which overcame some of the difficulties. It was necessary to lubricate the wire for metallic-shoe operation. This was an expensive procedure, and excess lubricant was deposited on the coaches and the street.

The success of carbon inserts in locomotive pantograph trolleys led to experiments in the use of carbon insert shoes. A satisfactory renewable carbon insert

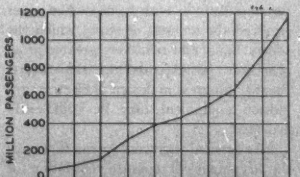

Figure 2. Ten-year record of transit passengers carried by trolley coaches in the United States

shoe has now been developed and is used extensively. The low contact pressures, self-lubrication, and current-collecting characteristics of the carbon are resulting in great improvement in life of overhead construction. As a result of these devices which are now available and probable future progress in design, material reductions in operating costs may be anticipated.

Maintenance of Equipment

Progress, which has been made in the vehicles themselves and the electric propulsion equipment, has effected economies in maintenance. The earlier 40-passenger coaches were propelled by two 65-horsepower motors. These were succeeded by a single 125-horsepower motor with a simplified control and with a double-reduction spur and bevel gear (or spur and hypoid) axle which proved to be superior in service to the worm-drive axles previously used.

Early trolley coaches had two principal items of maintenance: current collection and brakes. The former has been discussed. In the early days brake drums and linings were the same as those used on motorbusses. The trolley coach operates at higher speeds, and as a result there are more brake applications per hour, and those applications are made at higher vehicle speeds. Also the braking effect of an engine is absent. Life of brake lining and brake drums was very short. The single-motor axle provided more adequate braking equipment, but further improvement was desired.

This requirement was met by the introduction in 1938 of 140-horsepower motors with dynamic-braking control. A relatively small reduction in temperature of brake linings gives a relatively large increase in lining life. Standard practice is to provide an electric-braking rate of 2.0 miles per hour per second, whereas the total service braking rate is 3.0 to 4.0. This reduction of duty on the mechanical brakes has been sufficient to increase brake-lining life to five or six times the life obtained without electric braking. The life of the brake drums should be as long as the coach life. Reduced mechanical braking reduces tire temperature and thereby increases the life of the tires. More than 97 per cent of the trolley coaches purchased since 1938 are of the electric-braking type.

Trolley-coach maintenance in recent years has been approximately 2.70 cents per coach-mile, 0.90 cent of which is for tires and tubes. This amount should decrease as the mileage of modern vehicles expands. Modern streetcar maintenance

is 1.7 to 2.0 cents per mile. The maintenance of motorbusses of comparable size averages 4.0 to 5.0 cents per mile.

Power

The amount of power required for trolley coaches varies widely, depending on the conditions of operation. Greater weight, higher schedule speeds, hilly routes, and similar conditions increase energy consumption. The average energy consumption of 40-passenger trolley coaches according to recent American Transit Association data is 3.8 kilowatt-hours direct current per coach-mile. A modern streetcar requires approximately 5.4 kilowatt-hours per car-mile. The average cost of power is close to 1.0 cent per kilowatt-hour direct current.

The average cost of fuel and lubricants for 40-passenger motorbusses under similar conditions is approximately 4.0 cents per coach-mile, excluding gasoline tax which may be another 2.0 cents per coach-mile. Lubrication is a negligibly small item on trolley coaches but on motorbusses it is ten per cent or more of the fuel cost.

The central-station industry has a long record of decreasing the unit cost of power. Not only is the present power cost for the trolley coach favorable, but the prospects are that it actually will decrease. On the other hand, the future price of oil and gasoline is almost sure to increase. There is disagreement among the experts as to the adequacy of our supply of oil, even if we change our wasteful methods of use. One cannot expect any reduction in taxation of liquid fuels but should be prepared for increases.

Conducting Transportation

The principal item in public transportation expense is the wages of vehicle operators. At the present time wages per hour vary widely in different localities and among different types of vehicles. However, the cost of wages per vehicle-mile is inversely proportional to the schedule speed. The practically unlimited supply of power and the uninterrupted acceleration of the trolley coach give it marked advantage. It is true that some abnormally high-powered motorbusses may equal trolley-coach schedules, especially on brief test runs. However, in the same or identical service the trolley coach maintains schedule speeds 10 to 15 per cent higher than the usual motorbus. The power of trolley-coach propulsion equipment does not deteriorate with age and is practically independent of variations in air temperature and barometric pressure. Also the trolley coach is so easy to operate that driver fatigue does not reach the point where it affects schedule speeds.

In the long run administrative and general expense should be essentially the same for a given system regardless of the type of vehicle. At the present time different systems of accounts, different conditions with respect to insurance, and other items cause wide variations.

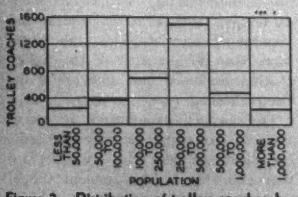

Figure 3. Distribution of trolley coaches by population groups

Table I

	Trolley Coach	Street-car	Motor-bus
Average seating capacity	44	52	29
Average passengers per one-way trip	31.8	38.4	17.9
Passengers per vehicle-hour	80	80.5	62
Operating cost per vehicle-hour less administrative and supervisory expense, per cent	100	141	107
Operating cost per passenger, per cent	100	140	138

Future Prospects

It is believed that the future of the trolley coach is particularly bright. New materials and new methods will result in lighter, more economical, and more attractive coaches. Also the motor bus has profited from the development of millions of private automobiles and tens of thousands of motorbusses. The modern streetcar is the result of an intensive development program costing hundreds of thousands of dollars. While the trolley coach has taken advantage of developments in both fields, it has never received the amount of study which the others have, and relatively greater progress may be expected in the future. Further progress in design of electric propulsion equipment may be confidently expected.

All electrical engineers are familiar with the advantages of separate ventilation for the efficient cooling of electric apparatus. Clean dry air results in improved motor commutator and brush performance especially where the air for self-ventilation has been full of dust and dirt. In the case of the trolley coach the motor losses stabilize the temperature of the air which is later blown over the resistors for coach heating. In many installations of dynamic-braking equipment, the resistor losses during acceleration and braking are frequently adequate for coach heating with only a small amount of supplemental heat from the line. In the colder climates a large proportion of the motor losses can be used for coach heating in the winter months. The fans designed for ventilation and running at constant speed require less energy than fans for motor self-ventilation which operate over the whole range of motor speed.

Table I shows an example of relative operating costs in a city having trolley-coach, streetcar, and motorbus service under generally similar conditions, except that the trolley coaches and motorbusses are modern. The streetcars are 20 years old. The motorbusses are of smaller capacity than the trolley coaches and operate under easier traffic conditions. When conditions permit, it is expected that trolley-coach service will supersede the streetcar service on all present carlines.

Figure 1 shows the number of trolley coaches owned in the United States by years from 1934 to 1943. As of December 1, 1943, there were 3,502 trolley coaches.

Figure 2 shows the number of passengers carried by trolley coaches each year from 1934 to 1943. Trolley-coach passengers were 0.6 per cent of total transit passengers in 1934 and 5.3 per cent in 1943. In cities between 50,000 and 1,000,000 population the trolley-coach passengers were 8.7 per cent of the total in 1943.

The number of trolley coaches owned in cities of various population classifications is shown in Figure 3. Cities between 100,000 and 1,000,000 have 76 per cent of the total; those between 250,000 and 500,000, 43 per cent.

Conclusion

Generalizations are frequently misleading, because there is no substitute for detailed analytical study of any problem. However, a number of studies indicate that the proper economic field for the trolley coach is that where the interval between vehicles during base hours is not less than four or five minutes and not longer than 15 to 20 minutes. It is realized that both of these limits vary widely under different conditions and that other considerations such as political

Aircraft Fuses Must Protect

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Synopsis: The ever-increasing list of electric equipment needed for the satisfactory performance of the modern airplane has brought the electric system from a place of relative unimportance to one which cannot be ignored. The electric equipment must not fail, particularly on combat planes. Therefore, the protective devices must be designed and applied to permit the equipment to function as long as it can supply any useful work but to remove it from the circuit when it has ceased to function or has become a hazard. This type of electrical protection is obtainable with fuses of special design when applied properly.

THE evolution of the electric system in aircraft has paralleled the development of the airplane itself. The original six-volt d-c electric system was little more complicated than that employed in the automobile. As power requirements increased, the voltage was increased to 12, then to 27 volts, which was considered adequate for several years. Increased electrical demands have forced the voltage still higher to 120 volts direct current in some installations, and now a 208-volt three-phase 400-cycle system has ceased to be merely a dream but will become a reality in the not too distant future.

Unfortunately, the transition from one system to the next has been so gradual that the whole problem of circuit and equipment protection has not been reviewed to see if a completely new or unorthodox approach could effect better results. The techniques of the six-volt system more or less have been transplanted to the higher-voltage systems without reevaluating them in the light of the requirements of the new system. Fortunately the 208-volt three-phase 400-cycle system will not permit such a transition, so that now is an ideal time to analyze what is available and what has been used to obtain more complete electrical protection in aircraft.

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Fusing Requirements

The fusing requirements in aircraft differ little from the results desired in industry except that the requirements and demands of the former are much more stringent. To save weight the overload capacity of aircraft electric equipment is reduced to an absolute minimum, whereas in normal power applications extra weight is not so objectionable.

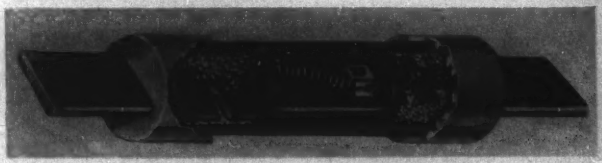

Figure 1. Time-delay fuse consisting of a heater, a thermally operable current interrupter, and a fast-acting short-circuiting member

Also, in aircraft the range of ambient temperatures to which a given installation is subjected is much greater than that found in normal power work. It is true that a power installation can be found where extremes in ambient temperatures may be experienced, but seldom, if ever, is one installation ever subjected to the range of −60 to +71 degrees centigrade as found in aircraft. Useless or unnecessary operation of protective devices in airplanes cannot be countenanced, particularly in military applications, whereas in most power applications objectionable operation of the protective device is seldom little more than a nuisance, hardly ever a catastrophe. Then the weight of the protection cannot be ignored in aircraft, thereby eliminating the use of many devices which have been proved satisfactory in industry. Hence, aircraft fusing can learn much from the techniques already employed in power work, but it must go further in accuracy to give the trouble free but complete protection required.

Electric fusing, whether it is applied to power work or aircraft, may be divided into two general categories:

1. Fuses to protect electric equipment.
2. Fuses to protect the circuit itself.

Consider first the practice now employed in power work. Since aircraft electric system voltages will not exceed 208 volts, the discussion can be limited to secondary power fusing.

Protection of Equipment

Electric equipment, with the exclusion of instruments and similar devices having practically no overload capacity, consists of a current-conducting path, usually metallic; insulation, either organic or inorganic; and a heat-absorbing mass, usually iron. The current-conducting path, insulation, and heat-absorbing mass are usually in good thermal relation, so that, under steady-state conditions, the heat generated in one member will elevate the temperature of all three components. Since the purpose of the electric equipment is to convert electric energy to mechanical, thermal, or chemical energy, and its efficiency is never 100 per cent, there always will be some electric energy converted to heat in the device so increasing its temperature.

When the equipment is subjected to slight overloads which are continued for appreciable times, failure will occur in the material which is damaged at the lowest temperature. Because there is time for heat conduction, the temperatures of the component parts of the equipment are elevated by the heat generated in the current-conducting path. This does not mean that there is not a temperature

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or financial affiliations sometimes dictate the course to be followed.

In the great majority of cities where trolley coaches have been tried on a reasonably large scale, their numbers have increased rapidly. Trolley coaches are the backbone of Seattle's transportation system, 292 being in use. Milwaukee has 274 coaches, Providence 204, Boston 162, Indianapolis 162, and Chicago 152. All of these latter cities started with relatively small initial installations and expanded them as a result of the favorable economic results. All of them contemplate further installations.

gradient in the device, but it does mean that this gradient remains unchanged if the load is maintained long enough to approach a stable condition. The point or temperature of failure, of course, is dependent upon the individual characteristics of the component parts of the device, but, once the various materials have been chosen, this point is established irrevocably. The overload may be the results of the malfunctioning of the electric equipment itself or may be due to a greater connected load than was anticipated in the design, but, in either case, the result is the same. In the final analysis this type failure may be regarded as a temperature failure even though it is caused by heat produced by electric energy. Hence, the condition is aggravated when operating in high ambient temperatures and alleviated in the lower ambient temperatures.

If the overload is increased, the length of time the equipment can withstand it is shortened, but, again, the mechanics of the failure is the elevation of the temperatures of the various component parts in their relative proportions until one fails. This process continues as the overloads are increased, the safe time steadily decreasing, but always dependent upon the thermal capacity of the whole device and influenced by the ambient conditions to which it is subjected. However, at some overload the heat generated in the current-conducting path will be so great that it will fuse before there is time to conduct some of the heat away from it to those components injured at a lower temperature. This type failure may be considered to be free from ambient effects, because the variation in ambient temperature, though theoretically affecting the failure in that less heat would be needed to cause failure at the higher ambient temperature, is so small a percentage that, for all practical purposes, its effect may be regarded as negligible. To illustrate the general theory, consider an electric motor. The current-conducting path is the copper wire; the insulation is enamel, rubber, glass, silk, or cotton used on the field windings; the heat-absorbing mass is the frame and rotor. On the lower overloads failure results from the insulation on the windings being destroyed, whereas on the higher overloads the copper in the winding itself actually fuses.

From this it is seen that the curve of the overload capacity or safe-operating characteristic of an electric device contains a point of inflection, because it is the combination of two curves having different slopes. The time–current curve of the copper is steep, whereas the curve in that region in which there is time for thermal conduction has a more gradual slope and is affected by ambient temperatures. A protective device, to give complete protection over the entire range without useless blows, must have the same characteristic. This characteristic cannot be produced by a single-element device, whether it be a fuse, circuit breaker, or thermal cutout. One answer to the problem is found in the time-delay fuse shown in Figure 1 time–current curve of which is shown in Figure 2. This device consists of a thermally operable current-interrupting device in series with a fast-operating short-circuiting member. Current flowing through the fuse generates heat in the heater as well as in the short-circuit strip. At the lower overloads most of the heat is supplied by the heater, but, as the overload is increased, the effect of the short-circuiting strip becomes more pronounced until finally, on the very high overloads where there is no time for thermal conduction, the fast-acting short-circuiting strip fuses before the thermally operable current interrupter can function. The time delay or time lag is obtained on the low overloads, because the heat generated in the heater must be conducted into the center member, called the absorber, and must elevate its temperature to the melting point of the fusible alloy holding the trigger before it can operate opening the circuit. The characteristics of this device are adjusted to approach the safe-operating characteristics of power electric devices, so that, if its rating is chosen correctly, complete electrical protection without useless blows is obtained. The melting point of the fusible alloy is chosen, so that the effect of ambient temperatures on the fuse is the same as on the electric device it is protecting. The time-delay fuse gives wonderful flexibility in design, because the heat-generating member, the fusible alloy, the mass of the absorber, and the characteristics of the short-circuiting strip can be adjusted independently giving any characteristic desired.

The United States Army Air Corps appreciated the potentialities of this type fuse and built their specification 94-32084 around it. Since, at the time the specification was written the highest system voltage in use was 27 volts, the short-circuiting characteristics were not specified. The specification covers the lower end of the curve by requiring the fuse to carry 110 per cent load indefinitely and to open at 125 per cent load within one hour and at 200 per cent load between 90 seconds and eight minutes. The omission of the unnecessary short-circuit requirements in the 94-32084 specification permitted a desirable saving in size and weight.

The fuse combining a fusible element with a thermally operable current interrupter is often condemned and precluded from aircraft applications, because it is felt that the increased protection is obtained only by increasing the weight which cannot be justified. Actually the use of such a fuse decreases instead of increases the weight of the protective device. This seeming anomaly is true, because the rating of the protective device can be decreased when time lag is built into it. To illustrate, consider a three-phase ten-horsepower 220-volt motor connected in series with ordinary fuses. Even though the full-load current of the motor is 27 amperes, 90-ampere fuses are used in the circuit to assure that the fuses do not blow under starting or transient conditions. Such a device only can furnish protection to the motor above 90 amperes. The fuse itself, neglecting the fuse block in which it is mounted, weighs 121 grams. If, instead of the conventional fuse, a fuse having a thermally operable circuit interrupter as well as a short-circuiting strip is used, the rating of this device can be reduced to 30 amperes, and still it has sufficient time lag to withstand starting and transient currents. With such a device the motor is protected over its entire range of overloads and short circuits by a device weighing only 20 grams. Therefore, the change from a conventional fuse to a time-delay fuse not only improves the protection obtained but, at the same time, effects a very desirable saving in weight, the time-delay device weighing only one-sixth that of the conventional fuse. If the blocks in which the fuses are mounted also are considered, the saving in weight is even more pronounced.

The counterparts of the commercial power fuses which have time lag and are of conventional design are found in the Air Corps specification 94-32084 and 32084-*B*. Specification 32084-*B* did not require the fuse to have any inherent time lag, its characteristic being comparable to a power fuse of conventional design. As already mentioned, specification 94-32084 required the time lag found in fuses combining a thermally operable current interrupter with a short-circuiting member. A 100-ampere 32084-*B* fuse needed for a 27-ampere motor weighs 71 grams, whereas a 30-ampere fuse made in accordance with specification 94-32084, giving complete protection to a 27-ampere motor, weighs only 22 grams. Therefore, contrary to the general conception, com-

plete protection is effected with a saving in weight instead of increasing the weight of the fuse, even though ampere for ampere the time-delay fuse weighs more.

As the ceiling of aircraft has been pushed steadily upward, the ambient-temperature range to which it is exposed has increased until now −60 to +71 degrees centigrade is not unreasonable to expect. Since the usual procedure is to mount the electrical protective devices in a central location, the equipment seldom would be exposed to the same ambient temperature as its protective device. Such a central or grouped mounting is necessary when circuit breakers combining a switch with electrical protection are used but is unnecessary when the switching operation is divorced from the protector as is possible with fuses. Then the fuse can be mounted wherever convenient, and, if the type and size fuse is chosen intelligently, the ease of replacement need not be a factor. The fuse only will operate when there is a case of trouble and the electric equipment it is protecting already has been operated to its thermal or electrical breaking point, so that replacement before clearing the trouble accomplishes nothing.

The extreme ambient requirements imposed upon all the airplane electric equipment have been appreciated, but no reasonable solution is possible so long as the electrical protective devices are subjected to ambient temperatures different from those to which the electric equipment itself is exposed. Since the normal grouping now employed in aircraft precludes the possibility of the equipment and protective-device ambient temperatures being the same, the effect is alleviated partially by making the electrical protective device irresponsive to ambient temperatures and then building enough overload capacity in the electric equipment so that it will function satisfactorily at the higher ambient temperature. Since the capacity of most electric equipment decreases with increasing temperature, it is overfused at the lower ambient temperatures and underfused at the higher ones, because the protective device is designed to operate purely on current, not ambient temperature. The net result is that accurate fusing is impossible as long as the protective device is not responsive to temperature in the same manner as the equipment it is protecting and as long as the time–current curve is not identical over the entire range of currents which flow through the equipment.

The time-delay fuse already described can be biased to give the same response to ambient conditions as the electric equipment it is protecting by choosing the operating point of its thermal interrupter properly. Since the operation of the thermal interrupter in the fuse is dependent on temperature resulting from the heat generated in the heater of the fuse as well as on the ambient temperature, the bias needed to compensate for any given range of ambient temperatures can be obtained by the choice of the operating point

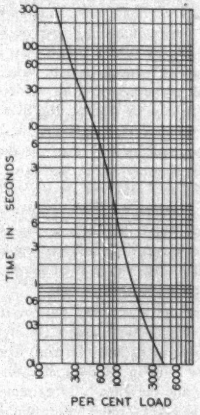

Figure 2. Time–current characteristic of the time-delay fuse shown in Figure 1

of the thermal interrupter. An even closer thermal relationship between the electric equipment and its protector is accomplished in power applications by mounting the time-delay fuse on the equipment itself in good thermal relation to the hot spot. This thermal relation is obtained by a metal pin which extends into the equipment from one terminal of the protective device. To improve the flexibility of the design, two points are provided which are responsive to thermal energy. The first, located between one terminal and the heat coil (see Figure 3), operates almost entirely from the heat supplied it by thermal conduction from the hot spot of the device being protected. The second thermal interrupter, located between the heat coil and the short-circuiting strip, is biased very slightly by the heat conducted to it from the hot spot, through the heat coil. In most cases the temperature of the heat coil is above that of the terminal, so that heat conduction from the terminal to the second interrupter through the coil is impossible, but the biasing effect of the thermal conduction from the hot spot is realized in that the terminal temperature is elevated by it, so reducing the temperature gradient from the thermal center of the coil to the terminal and therefore reducing the heat conduction, thereby forcing more of the heat generated in the coil to flow into the second thermal interrupter. The operation of the thermal interrupter between the heat coil and the short-circuiting strip is due primarily to the heat generated in the heat coil and is a function of the current flowing through it. Since the heat must be conducted from the coil to the interrupter, a time lag is obtained which can be varied by varying the mass of the thermal interrupter or by varying the length of the thermal path through the heat coil. The short-circuiting strip, of course, is designed to be fast acting, but its rating is so chosen that it does not function until the higher overloads, approaching short-circuit conditions, are realized.

Such a protective device has proved its worth in industry. The flexibility of its design permits the time–current curve to be made the same shape as that of the equipment it is protecting, so that complete protection is furnished over the entire operating range of the equipment under any ambient conditions. It will operate, protecting the equipment, whenever the temperature of the hot spot exceeds a safe predetermined temperature. Again the only answer to the objection that the protective device is unsuited for aircraft applications, because it often must be mounted in an inaccessible place which cannot be reached in flight, is that such a protective device eliminates the guesswork in fusing so that the protective device only will function when the equipment is worthless. The continued use of the equipment under such conditions only will disturb the electric system if not injure it without producing any useful work. If the equipment itself is accessible enough to be repaired in flight, then, obviously, the protective device also is replaceable, so that, in either case, the positive reliable performance of a properly

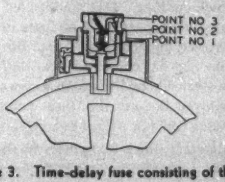

Figure 3. Time-delay fuse consisting of three interrupters in series

Point 1 is responsive to the heat conducted to it from the device being protected, point 2 is responsive to the heat conducted to it from the heat coil, and point 3 is a fast-acting short-circuiting member functioning at high overloads

designed and properly selected protective device cannot be criticized.

Such a time-delay fuse never has been adapted to aircraft applications, but it could be made quite attractive from a weight angle, because the present commercial model, in which weight has not been given any special consideration, weighs only 23 grams for a ten-ampere rating, whereas a 94-32084 fuse of the same rating weighs 18 grams. Hence, a few minor design changes probably could reduce the weight to a figure quite comparable with that of the 94-32084 fuses which have proved quite satisfactory.

Circuit Protection

The problem of circuit protection as distinct from the protection of electric equipment is being attacked from two angles, both of which have their advantages and limitations. The first may be termed circuit isolation, its principal function being to isolate heavy faults and remove the load from the system to prevent the overloading of the generators supplying it. The second may be termed circuit protection in that the protective device is chosen so that it will function as a result of damaging overloads as well as faults, to remove the excessive load from the system. In either type of circuit protection, fuse co ordination, both with the branch circuit fuses and the equipment fuses, must be considered to prevent cascading and the blowing of fuses which will de-energize more than the absolute minimum of equipment under fault conditions. Fortunately, on the 27-volt systems the co-ordination problem was quite simple, because a transmission system of the simplest sort was employed, and the number of points at which cascading could occur was few if any. Because of this, fuse co-ordination was accomplished by increasing the rating of the feeder fuses inordinately to prevent them blowing under fault conditions in any of the branch circuits. This practice led to the use of limiters instead of fuses in these overfused applications. Since the rating of the fuse was chosen so great that under low overload conditions the wire would be destroyed before the fuse functioned, nothing could be gained by using a fuse.

Limiters differ from fuses in that the fusing current of a limiter is great compared to the safe carrying current, whereas in a fuse the difference between the carrying current and the opening current is small. Since the limiter link usually is made of copper, silver, or other high-melting materials, there is a range of currents between the safe carrying current and the fusing current which, if continued long enough, will destroy the device itself as well as equipment in good thermal relation to it. The fuse, on the other hand, will carry or blow, depending upon the current, without ever reaching a damaging temperature. Hence, the current limiter can be compared to the fast-acting short-circuiting strip which is combined with the thermal interrupter in the time-lag fuses already described. The aircraft limiters are an adaptation of those devices used in power work which originally were little more than a cable lug with a reduced section. Their function in underground work was to assure that, in case of trouble, the blow would occur in the manhole where the limiters are mounted instead of in the duct run, thereby simplifying the clearing of trouble and the restoration of service. This feature of the limiter is of no great value in aircraft where the conduit runs are short and particularly in military applications in which open wiring is employed almost universally.

Since the limiter will destroy itself on slight overloads because of the high melting point of its link material, it is satisfactory only in clearing short-circuit or high fault currents. Its extremely low time lag gives a wider separation of blowing times between limiters of different ratings at the same current, so that coordination is relatively simple. Therefore, limiters permit the isolation of faults producing high fault currents, but on low currents they are worse than no protection at all, because they in themselves produce a fire hazard and destroy equipment associated with them.

The fault currents resulting in an electric system are dependent not only on the impedance of the fault but also on the capacity of the generating equipment. Of course, the higher the voltage, all other conditions being equal, the greater will be these currents. Hence, on the 27-volt systems the fault currents may be expected to be relatively small, whereas those encountered in the 208-volt systems will assume reasonable proportions. However, the impedance at 400 cycles will reduce these currents, so that it is not at all unreasonable to assume that low fault currents can be obtained in aircraft. As long as these currents are not great enough to injure the wire insulation, there is no reason for them to be cleared instantly, particularly if the isolation of the fault will, at the same time, isolate equipment which is functioning properly. Instead, it would be better to permit the fault to persist until the completion of the mission and then be cleared when the airplane had returned to its base. Many of the wire sizes in aircraft are chosen from a voltage-drop standpoint instead of a thermal one, so that low fault currents will produce no damage to the distribution system and will affect the equipment only in that the voltage at its terminals will be reduced because of the increased voltage drop in the line. If this drop is sufficient to cause the equipment to overheat, it will be protected by its own protective device, so that the circuit protective devices need not function in this eventuality. If the fault current is so great that the thermal capacity of the wire itself is insufficient to withstand the heat generated in it, the fault must be isolated if complete protection is to be realized.

To obtain complete protection of the electric distribution system, the problem again reverts to a consideration of the combined thermal capacity of the insulation and copper of the conductors. Again the protective device's time–current characteristic must be identical with that of the conductor to give complete protection under all conditions of load. Since the thermal capacity of the conductor is less than that of most electric equipment, the time lag of the circuit protective device need not be so great as that of the equipment protection. This problem was appreciated by the United States Army Air Corps and was covered by specification 94-32272. The time lag required in the most recent issue of this specification is a minimum of 40 seconds as compared to 90 seconds in the 94-32084 specification covering protective devices for electric equipment.

The effect of ambient temperature on the carrying capacity of the wires is as important as its effect on the capacity of electric equipment, so that again a protective device responsive to ambient temperatures in the same proportion as the wires and mounted in the same ambient temperature is needed. This is not so unreasonable as it appears on the surface, because the use of glass insulation on the wires permits a relatively high safe-operating temperature, so that the effect of the ambient temperature on the protective device need not be too pronounced. Also, the grouping of sectionalizing fuses in a common central cabinet which may be subjected to ambient temperatures very different from those of the wire is unreasonable, both from a safety angle in military aircraft and from a functional angle. Grouping the devices together necessitates the use of additional wire which, in turn, should require additional sectionalizing fuses for complete fault isolation.

Therefore, the circuit fuses can be mounted in approximately the same ambient temperature as the circuit wires and, though not so responsive to ambient temperature as the equipment protection, still should respond in the same manner as the circuit conductor.

By using a time-lag fuse of the design shown in Figure 1 but with the absorber mass decreased and the thermally operable current interrupter biased to be less responsive to ambient conditions than the equipment protective device, a saving in weight is accomplished, and a circuit protective device is obtained which will co-ordinate beautifully with the equipment protector. Since both the equipment and the circuit protectors have fast-acting short-circuiting members, excellent co-ordination is obtained at the higher overloads with complete protection to equipment and circuit under every conceivable condition of overload and ambient temperature. Thus, by adapting an arrangement already proved in power applications, aircraft can avoid many headaches, if not catastrophes, as its power system grows from that of an automobile to that of a power network.

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Switchgear and Control for an Electronic Power Converter

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Synopsis: The electronic power converter, controlled by the equipment described in this paper, consists of two units rated 10,000 kw installed and operating at the Edgar Thomson Works of the Carnegie-Illinois Steel Corporation. The power converters connect a 60-cycle 69-kv system and a 25-cycle 44-kv system with a permissible power transfer of 20,000 kw in either direction between the systems. Transfer of power by rectification and inversion and the design of the electronic power converter are discussed in companion papers.[1,2] The switchgear and control devices are discussed in this paper and for convenience and clarity, the discussion is divided into three main headings: "Switching," "Control," and "Protection."

TO the switchgear designer whose point of view is influenced so largely by the needs of the "man who operates and maintains," the electronic power converter presents some new and interesting opportunities. The ease with which the converter is switched in o and out of service and its output is controlled presents the opportunity of providing simple and at the same time versatile controls by means of which the operator can make the fullest use of the converter, in meeting the varying demands of his system. Protective relaying of the electronic converter against system disturbances is simple since the rectifier furnishes no power to its system and the output of the inverter is limited.

Switching

An examination of Figure 1 will reveal that the switching of the main power circuits of the electronic power converter is of the simplest possible nature. The unit is switched into service merely by closing power circuit breakers connecting the transformers to the two systems. Aside from having the auxiliary and ignition bus energized by closing the auxiliary and ignition transformer switch and circuit breaker, the only prerequisite to putting the unit into service is that the ignition-control-system networks for both frequencies must be in the inverter position. Auxiliary switches on the circuit breakers and position switches on the power-control device provide circuits for establishing this condition whenever the circuit breakers are tripped, and simple interlocking in the circuit-breaker control circuits insures it. Therefore, the sequence of closing the breakers is of no consequence, and either breaker may be closed first, regardless of the intended direction of power flow. For convenience and simplicity of protective-relay circuits, both breakers are tripped simul-

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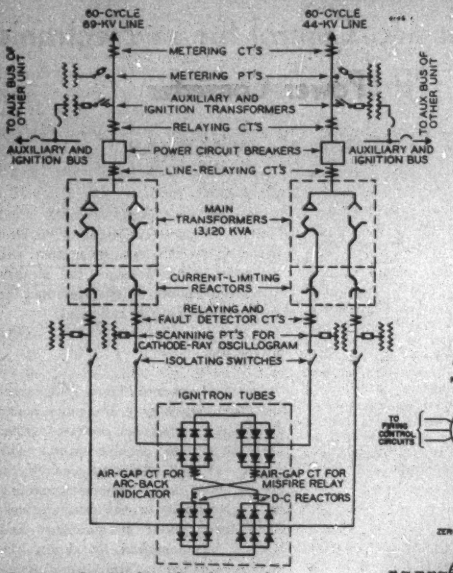

Figure 1. Simplified one-line diagram showing switching equipment

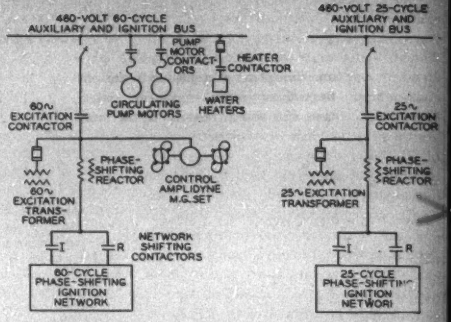

Figure 2. Switching equipment for auxiliary apparatus

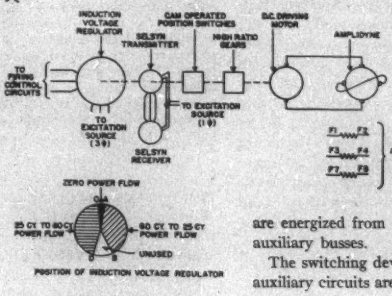

Figure 3. Control device for power flow through the power converter

taneously at all times. Circuit-breaker operation is the only switching operation required under normal operating conditions.

The only switching required in the circuits between the ignitron tubes and the transformers is that required for safety to personnel who may have occasion to work on equipment in the tube assembly enclosure. For this purpose, enclosed group-operated disconnecting switches are provided, suitably key-interlocked with tube-enclosure doors and high-voltage power circuit breakers to insure safety and to prevent operation of the switches under load.

Since the flow of power in the d-c portion of the circuit is under complete control of the grids of the rectifier and inverter tubes, there is no necessity for any switching apparatus in the d-c circuit.

Switching of the auxiliary and ignition transformers to the high-voltage lines is accomplished by horn-gap disconnecting switches suitable for interrupting magnetizing current of the transformers. These switches are suitably key-interlocked with the transformer secondary air circuit breakers to prevent their operation under load. The transformers are protected by suitable current-limiting fuses.

The 460-volt secondary windings of the auxiliary and ignition transformers are connected to their respective loads by means of manually operated air circuit breakers. The transformers have sufficient capacity to carry the auxiliary and ignition load of both units. Provision is made therefore by means of a tie air circuit breaker for energizing both unit auxiliary busses from one transformer in case the other is out of service for any reason.

Each power converter requires the following general auxiliary devices, which for the sake of utilizing standard apparatus are energized from the 60-cycle auxiliary bus:

Driving motor for main control Amplidyne generators.

Cooling-water circulating-pump motors.

Water heaters.

The phase-shifting networks which supply the ignition equipment for the 60- and 25-cycle tube assemblies are energized from the 60- and 25-cycle auxiliary busses, respectively, through selector contactors which determine whether the tube assembly is to operate as a rectifier or inverter.

Similarly, excitation transformers, supplying dry-plate rectifiers for the excitation of the main control Amplidynes, are energized from the 60- and 25-cycle auxiliary busses.

The switching devices in these various auxiliary circuits are shown in Figure 2.

Control

When switching of the power circuits has been completed as previously described, the power converter is ready for control of direction and magnitude of power flow. The explanation under this heading will cover the means by which the power flow through the power converter is controlled. The operator has a choice of three types of control: manual control by control switch, or either of two types of regulator control—watt regulator or load regulator. The paragraphs which follow first deal with the devices common to all three types of control, and then the three types of control are individually briefly explained.

The direction of power flow through a power converter is determined by the connections of the phase-shifting ignition networks to the auxiliary and ignition bus as discussed in a companion paper. These connections are made by contactors *I* or *R* of Figure 2; when the *I* contactor is closed, the phase-shifting ignition network causes the tubes connected to that network to operate as inverters; when the *R* contactor is closed, the phase-shifting ignition network causes the tubes connected to that network to operate as rectifiers. Therefore, for

example, to have power flow through the converter from the 60-cycle system to the 25-cycle system, the *R* contactor of the 60-cycle network is closed and the *I* contactor of the 25-cycle network is closed. The *I* and *R* contactors therefore are the direct means by which direction of power flow is established. The control of those contactors is described in the following paragraphs.

The magnitude of power flow through a power converter is determined by the magnitude of the reference voltage used in the field circuits of the control Amplidyne associated with the firing circuits, as discussed in a companion paper.[2] The reference voltage is obtained from an induction voltage regulator, and the magnitude of that voltage is determined by the induction regulator's rotor position. Control of the rotation of the induction-regulator rotor therefore is the direct means by which the power-converter load is controlled.

The power-control device is shown in Figure 3. The rotor of the induction regulator, the Selsyn transmitter, and the cam-operated position switches are on a common shaft; the shaft is driven through a high-ratio gear box to give smooth vernier control of shaft position. Contacts of the cam-operated position switch control the *I* and *R* contactors (of Figure 2). For the position of the induction regulator corresponding to 90 degrees retard excitation and (zero power flow) for rectifiers, as discussed in a companion paper,[2] the contacts of the cam-operated position switch cause the *I* contactors of both the 25-cycle and 60-cycle networks to be closed, and all tubes of the power converter operate as inverters. As the induction-regulator rotor is moved away from this position of zero power flow, by means of contacts of the cam-operated position switches, the *I* contactor of one of the networks is opened and the *R* contactor is closed, making the power converter capable of power transfer; for one direction of rotation of the induction-regulator rotor from its zero power flow position the *R* contactor of the 25-cycle network is closed, and for the other direction of rotation the *R* contactor of the 60-cycle network is closed. Also, as the induction-regulator rotor is rotated in either direction from the zero-power-flow position, its output voltage magnitude is varied to give smooth increase from zero to maximum power flow as discussed in a companion paper.[2] The power flow through the power converter for different positions of the induction-regulator rotor is illustrated in Figure 3 (below the induction voltage regulator); this illustration represents 360 mechanical degrees of rotation of the rotor. It is at points *A* and *C* that the *R* contactor of the 60-cycle or 25-cycle network, respectively, closes and remains closed over the travel represented by the cross-hatched areas in the illustration. Rotor rotation from *A* to *B* or from *C* to *D* represents gradual smooth increase in power flow from zero to maximum for either direction of power flow as marked. Two contacts of the cam-operated position switch act as limit switches and prevent travel of the induction-regulator rotor beyond points *B* and *D*. Indication of the position of the induction regulator is obtained on the control board from the Selsyn receiver shown in Figure 3.

Driving power for the shaft driving the induction regulator, Selsyn, and cam-operated position switches is obtained from a d-c motor whose armature is energized by an Amplidyne generator. The use of a generator rather than a constant potential d-c source to energize the d-c motor has the advantages of:

1. Reversible rotation of the d-c motor without the use of reversing contactors.
2. Easy adjustment of d-c-motor armature voltage magnitudes.
3. Easy adoption of control circuits.
4. Inherent dynamic braking.

The Amplidyne is used instead of a conventional d-c generator, because its low excitation requirements permit the use of relay and control-switch contacts directly in its field circuit; the control fields of the Amplidynes used require only 0.1 ampere for 300-volt output; also these control fields have a resistance of only 218 ohms which permits the use of low control voltages.

The Amplidyne has three fields, two control fields designated as *F*1-*F*2 and *F*3-*F*4 and one field designated as *F*7-*F*8 used for antihunt and residual voltage killing. To produce rotation of the d-c motor, voltage is applied to one of the Amplidyne control fields. Either direction of rotation is obtained as desired, since the control circuits apply a voltage of either polarity to a given field terminal. Separate "raise" and "lower" speed adjustments are provided, since operating engineers may find it desirable to decrease the load setting at a faster rate than the load setting is increased, or vice versa. A fault-blocking contact in the control-field circuits opens during arc-backs or other faults within the power converter; this prevents change in the setting of the induction voltage regulator during such faults while the fault-recovery equipment is functioning.

As stated in the section on switching, the main circuit breakers can be closed only if excitation power is available and if both the 25-cycle and 60-cycle portions of the converter are operating as inverters. To insure that excitation is present, an undervoltage relay is connected to the auxiliary and ignition bus (Figure 1), and its contact permits the breakers to close only when proper voltage is present. Contacts of the cam-operated position switch (Figure 3) prevent closing of the breakers except when the induction voltage regulator is in its zero-power-flow position where all tubes operate as inverters. If the circuit breakers are tripped while the converter is carrying load, the induction regulator automatically is returned to its zero-power-flow position.

Manual control of power flow is by means of a simple double-throw momentary-contact control switch. Amplidyne field *F*3-*F*4 is used for manual control, one position of the control switch connecting terminal *F*3 to positive potential, and the other position of the switch connecting terminal *F*3 to negative potential (control potential is 24 volts direct current). An operator, therefore, merely turns this control switch in the position to give the desired direction of power flow, and the switch is held in that position until power flow has increased to the desired magnitude as indicated by a wattmeter on the control board.

The watt regulator is a device for regulating automatically the power flow through the power converter. The power elements of the device are connected to the current transformers and potential transformers in the power circuit of the power converter (Figure 1); the potential elements are correctly connected to the potential transformers for either direction of power flow by means of contacts of the position switches. The watt regulator has two sets of contacts; one set of contacts is closed when the power-converter power flow is greater than the regulator calibration, and the other set of contacts is closed when the converter power flow is less than the regulator calibration; both sets of contacts are open when the converter power flow is equal to or within approximately ±2 per cent of the regulator calibration. Calibration of the device is changed by means of a control switch on the control board; an instrument is provided on the control board which indicates the calibration setting directly in kilowatts.

Figure 4. Control-room panels and excitation cubicles for 10,000-kw electronic power converters

Figure 5. Load-control panels for each converter unit and test panel at right

The two sets of contacts connect the Amplidyne control field to control voltage of correct polarity to cause the induction voltage regulator rotor to be rotated in the direction to correct the power flow; for example, if the power flowing through the converter is less than the setting of the watt regulator, its contacts connect the Amplidyne control field to the potential which will cause the d-c motor to rotate the induction regulator rotor in the direction to increase power flow through the power converter. Amplidyne control field *F*3-*F*4 is used for watt regulator control as well as for manual control. With the watt-regulator control switch in the "on" position, the regulator contacts are connected to field *F*3-*F*4 and the manual-control-switch contact circuits are disconnected. Contacts of the cam-operated position switch connect the regulator contacts to the control voltage polarity which gives correct direction of rotation of the induction voltage regulator for either direction of power flow in the frequency changer. In putting a power converter on watt regulator control, it is initially necessary for the operator to select direction of power flow by means of the manual-control switch; once the induction-voltage regulator has arrived at either position *A* or position *C* (Figure 3), the regulator control switch can be turned to the "on" position, and the regulator functions to pick up the load for which the regulator is set.

The load regulator is an indicating integrating device energized from current and potential transformers which measure the interchange of power between the power company's system and the industrial company's 60-cycle system. The load regulator is designed to hold a preselected value of instantaneous exchange kilowatts. This value, however, is corrected to compensate for any differential between the ideal preselected kilowatt-hour exchange and the actual kilowatt-hour exchange as time progresses.

The load regulator permits the industrial user to make the best possible exchange of kilowatt-hours with the power company as determined by his contract with the power company. When the 60-cycle industrial load is heavier than the setting of the load regulator, the power converter supplies kilowatt-hours from the 25-cycle system to the 60-cycle system; when the 60-cycle industrial load is smaller than the setting of the load regulator, the power converter supplies kilowatt-hours from the 60-cycle system to the 25-cycle system. The contacts of the load regulator connect Amplidyne field *F*1-*F*2 to the control voltage polarity which correctly adjusts the power flow through the power converter. The load regulator is made operative or is removed from operation by a two-position control switch.

For the station described, which has two converters, the load regulator can be used to control either or both converters by selecting such operation by means of the control switches. When both power converters are operated on load-regulator control, load-balance relays are made operative. The load-balance relays are two-element induction-disk devices whose current circuits are energized from differentially connected current-transformer circuits of the two power converters. These relays keep the loads on the two power converters approximately equal when both are controlled by the load regulator.

Any of the types of control described, manual, watt-regulator or load-regulator, can be used on one converter without regard for the type of control being used on the other. While the operator has a versatile choice of control combinations at his disposal, there are no complicated operating sequences which must be followed.

Protection

For the purpose of discussion of protective relaying, faults which must be considered may be classified and subclassified as follows:

1. Faults associated with the converter its transformers, and auxiliary apparatus
(*a*). Insulation failures in the transformer and a-c conductor system.
(*b*). Malfunction of the ignitron tubes or insulation failure in the d-c conductor system accompanied by failure or too frequent operation of the automatic fault-suppression features of the converter grid and ignition control.
2. Faults associated with the power systems
(*a*). Short circuits.
(*b*). Loss of voltage.

Insulation failures in the transformers and a-c conductor system are treated in the same manner as similar faults in conventional transformers. It is impractical to apply differential relays to rectifier transformers by reason of the complexity of their secondary windings and the peculiar character of the currents flowing in these windings. Therefore, the best available protective relay for this purpose is the short-time-delay induction overcurrent relay with an inverse characteristic. This relay is adjusted to have just sufficient minimum time delay (approximately 0.05 second) to allow for normal transformer magnetizing inrush currents and short-duration fault currents resulting from transient disturbances in the ignitron tubes. On systems having impedance-grounded neutrals a sensitive residual overcurrent relay also is used to clear ground faults.

Normal suppression of arc-backs and "shoot-throughs" in the rectifier and inverter tubes and d-c short circuits by

the converter ignition and grid-control equipment and the igniter short-circuiting device has been discussed in a companion paper[1] describing that equipment. Operating experience so far has developed no failure of the fault-suppression equipment to clear arc-backs, "shoot-throughs" and d-c short circuits. However, such a possibility, though considered very remote, must be guarded against by backup protective relays which will prevent damage to the apparatus under such circumstances.

Rectifier arc-backs which are not cleared by the normal fault-suppression apparatus will result in sustained overcurrent in the rectifier transformer secondary winding of sufficient magnitude to cause the transformer protective overcurrent relays in this circuit to operate.

Inverter "shoot-throughs" and d-c short circuits which are not cleared by the normal fault-suppression apparatus will result in sustained overcurrents in the rectifier transformer and will produce alternating overcurrents in the lines between the rectifier tubes and the transformer; sensitive and effective protection is obtained by the use of short-time induction overcurrent relays connected to current transformers in these lines.

In the case of repeated arc-backs or "shoot-throughs," the fault-suppression apparatus merely will suppress these faults as fast as they occur, and some means must be provided for disconnecting the converter when such faulting occurs. Since each fault suppression is accompanied by a transient operation of an igniter short-circuiting device, impulses from the operation of this device are used to actuate a relay which operates to trip the power circuit breakers if the impulses occur too rapidly for predetermined time. The relay used for this purpose is a combined time-delay and notching device which, when subjected to more than a predetermined number of impulses within a predetermined period of time, closes its contacts to trip the power circuit breakers.

Short circuits on the supply system tend to reduce the voltage of that system. This reduced voltage applied to the rectifier tends to decrease the normal flow of power from the supply system to the receiving system. Since the inverter cannot function as a rectifier or the rectifier as an inverter unless the grid controls purposely are changed to give such operation, the converter cannot transfer power from the receiving system to the supply system.

Short circuits on the receiving system are of such a nature that they do not reduce the voltage of that system below approximately 80 per cent of normal will cause the converter to deliver only a nominal increase in power to the receiving system, but never more than the upper limit of power transfer provided for in the converter control.

Short circuits on the receiving system of sufficiently low impedance and on any or all phases will cause the inverter to cease to commutate the direct current. This in effect places a short circuit on the d-c system. The rectifier control immediately limits this direct current to normal maximum load current, but the inverter immediately ceases to deliver power to the receiving system. As soon as the fault on the receiving system is cleared and the voltage returns to normal, the inverter begins to commutate again and delivers normal power to the receiving system.

As previously noted, low voltage, either single- or three-phase, on the supply system merely decreases the normal flow of power or, if it is too low, causes the rectifier to cease firing, thereby interrupting the flow of power. Low voltage, either single- or three-phase, on the receiving system either causes a nominal increase in power flow or causes the inverter to cease commutation, thereby interrupting power flow.

It becomes evident, therefore, that only in case of prolonged low voltage on the receiving system, sufficient to cause a cessation of inverter commutation, is it necessary to disconnect the converter from the system. This is accomplished readily by means of a single- or three-phase time-delay undervoltage relay set to drop out at approximately 80 per cent of normal voltage and having sufficient time delay to permit system relaying to remove receiving-system short circuits.

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Differential Generator Control Relay for D-C Aircraft Electric Systems

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Synopsis: The definite-pickup type of generator control relay has been in use for a period of years on d-c aircraft electrical systems. While this type of generator control relay gives satisfactory operation when the system is in proper adjustment, it had disadvantages which are accentuated by improper adjustments of regulators and the relays. A differential type of generator control relay not subject to chatter has been developed and tested in flight on a system having four main-engine-driven generators and an auxiliary power plant. This type of relay has been shown practical and advantageous when used on a system having voltage regulators with equalizers.

Functions of Generator Control Relay

THE principal function of a generator control relay on aircraft d-c electrical systems is to connect the generator to the ship's d-c bus whenever the generator is in a condition to furnish power to the bus, and to disconnect the generator from the system whenever the generator draws reverse current from the bus above a predetermined value. The relay also provides a means of disconnecting or holding off any generator at the will of the operator.

The Definite-Voltage-Pickup Type of Relay

In the past on 28.5-volt d-c electrical systems, a relay of the voltage-pickup type has been in common use. Such a scheme is illustrated schematically in Figure 1.

The voltage-pickup type of generator control relay consists of a main contactor energized from the generator ter-

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The tests referred to in this paper and oscillograms were taken in flight by R. H. Kauffman and C. W. Hanson of the General Electric Company.

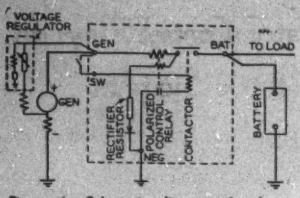


Figure 1. Schematic diagram of voltage-pickup type of generator control relay

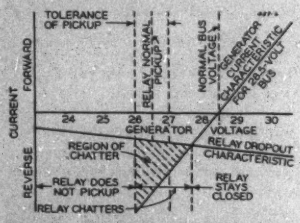


Figure 2. Characteristics of definite-voltage-pickup type of generator control relay and system

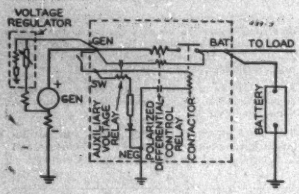


Figure 3. Schematic connections of differential generator control relay

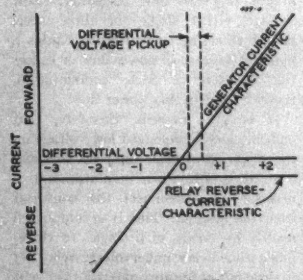


Figure 4. Characteristics of differential generator control relay and system

minal voltage through contacts on a polarized control relay having a voltage coil and a current coil. The characteristics of relays of this type are a definite voltage pickup and a dropout on reverse current which is a function of the voltage on the voltage coil, that is, it requires a higher value of reverse current to drop the relay out at 28.5 volts than

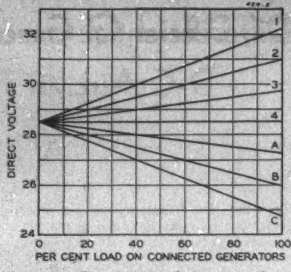


Figure 5. Characteristics of generator voltage regulators with equalizers on four-generator system

Curves 1, 2, 3—Characteristics of regulators on machines off the bus

Curves A, B, C—Characteristics of regulators on connected machines

Curve 4—Characteristics of regulators with all machines on

Curves 1 and A—One machine off, three machines on

Curves 2 and B—Two machines off, two machines on

Curves 3 and C—Three machines off, one machine on

at a lower voltage such as 27.0 volts. Typical characteristics of such a relay are shown in Figure 2, together with the system current characteristic for an assumed bus voltage of 28.5 volts established by other generators already on the bus. By reference to this figure, it can be seen that there is a shaded region above the pickup voltage of the relay where the relay will pick up and immediately upon closure draw a reverse current sufficient to drop it out and result in a chattering condition so long as the generator operates at a voltage in this region.

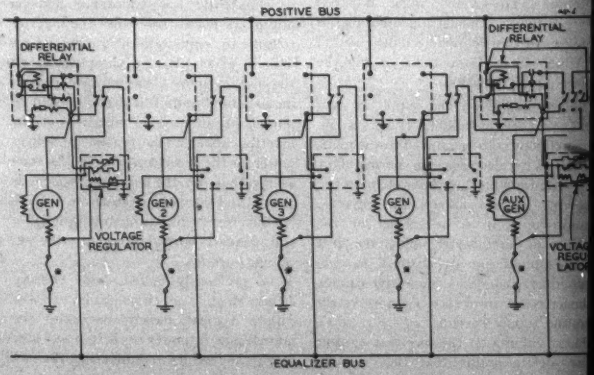
Each time a generator comes up in speed, it operates in this region and the relay will chatter unless the generator speed is brought up so rapidly that the time duration of operation in this region is so short that the chatter does not occur. A second reason why a generator may operate in this region is in case the system load is light and its voltage regulator is set low in voltage with respect to the setting of voltage regulators on other generators operating in parallel. This is the most dangerous type of chatter because it is more likely to persist for long periods of time. It has been a real source of trouble on present systems in military service as it may result in hundreds of thousands of operations of the relay in a few hours giving rise to rapid wear. The chatter may be minimized or eliminated by raising the pickup voltage, increasing the reverse current characteristic of the relay, and by making sure that voltage regulator settings and connections are proper. If these things are done, the system is practical.

The Differential Type of Generator Control Relay

A second type of relay operating on a different principle has been developed which has several advantages which will become apparent as its characteristics are examined. This is known as a differential type of generator control relay and is the chief subject of this paper. Typical connections of such a relay are shown in Figure 3. Referring to Figure 3, the differential generator control relay consists of a main contactor energize-

Figure 6. Schematic connections of 28.5-volt d-c system with four main generators and one auxiliary power plant

* 0.5-volt drop in negative lead for 100 per cent rated current of generator



through a contact on the differential control relay and a manual switch from the generator voltage. The differential control relay is a polarized device having a series coil and a voltage coil. The voltage coil is connected across the contacts of the main contactor through a contact on a small polarized voltage relay. The function of this latter voltage relay is to protect the differential voltage coil for large differential voltages and to prevent drain on the batteries in case the battery switches are left closed when the plane is not in operation. The characteristics of the differential relay are that it will close whenever the voltage of the generator is above the bus voltage by from 0.2 to 0.5 volt and it will drop out at a definite value of reverse current independent of the voltage of the generator. These characteristics are shown in Figure 4, together with the system current characteristic. It can be seen from this figure that there is no region of chatter because the relay will not close the generator on the bus under any condition where it will cause flow of reverse current. Likewise the relay will not automatically remove the generator from the bus on reverse current under a voltage condition that would cause it to reclose.

It might be argued that such operation could be obtained with a voltage pickup type of relay if the pickup voltage were raised to a point equal to or above the bus voltage. This is true but is not easy of attainment because of the necessary tolerance of pickup. On the differential type of relay a given percentage tolerance in the differential voltage results in only a small difference in generator voltage whereas the same percentage tolerance on the voltage-pickup type would result in a much wider variation in the actual pickup voltage. The differential type has another advantage in that the pickup voltage is related to the bus voltage so that if the bus voltage is low, the generators can come on at a lower speed and thus charge low batteries at a generator speed that could not generate enough voltage of cause a definite-voltage pickup type of relay to operate.

Effect of Equalizers on Voltage Regulators in Supplementing Differential Generator Control Relays

It is to be noted that the differential type of generator control relay will close the generator on only when the generator voltage is of correct polarity and above the bus voltage. This brings up a question on a system where generators are operating in parallel with all voltage regulators set at the same voltage as to whether the first generator to come on the bus will not raise the bus voltage to a point where the other generator control relays cannot close their generators on. Were it not for the presence of equalizing windings on the voltage regulators, this might be a valid objection. However, with equalizer windings on the regulators, any load on the connected generators will not only cause the voltage of the connected generators to droop with an increase in load but will also cause the voltage of the generators not on the bus

E_B = Bus voltage
E_{R1} = Contactor-coil voltage, relay 1
E_{R2} = Contactor-coil voltage, relay 2
I_1 = Current through relay 1
I_2 = Current through relay 2

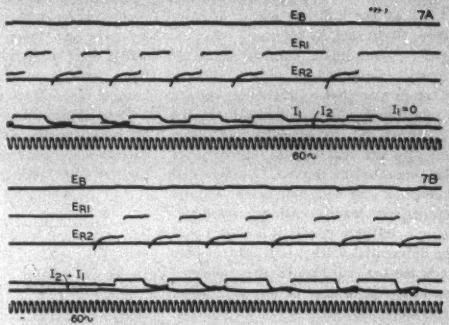
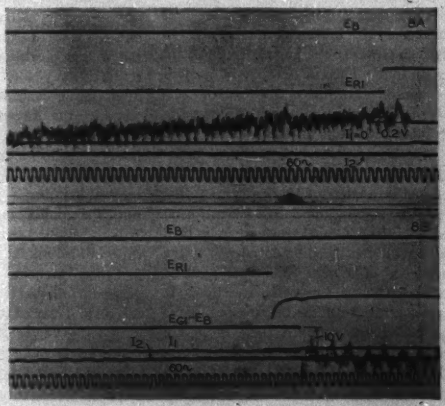


Figure 7A (upper). Oscillogram showing action at pickup on voltage-pickup type of generator control relay, taken by slowly increasing voltage setting of incoming generator regulator

Figure 7B (lower). Oscillogram showing action at dropout on voltage-pickup type of generator control relay, taken by slowly decreasing voltage of generator regulator

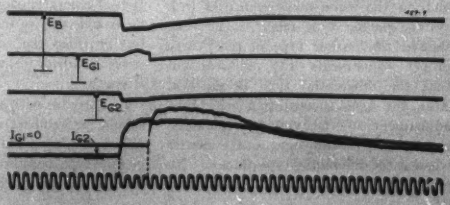
Figure 8A (upper). Oscillogram showing action at pickup on differential type of generator control relay, taken by slowly increasing voltage setting of incoming generator regulator

Figure 8B (lower). Oscillogram showing action at dropout on differential type of generator control relay, taken by slowly decreasing voltage of generator regulator



E_B = Bus voltage
E_{R1} = Contactor-coil voltage, relay 1
$E_{G1}-E_B$ = Differential voltage
I_1 = Current through relay 1
I_2 = Current through relay 2

Figure 9. Oscillogram showing pickup of one differential relay upon application of heavy (turret) load. Relay previously held off by low setting of voltage regulator



E_B = Bus voltage
E_{G1} = Voltage, generator 1
E_{G2} = Voltage, generator 2
I_{G1} = Current, generator 1
I_{G2} = Current, generator 2

to rise as the load increases. This action is illustrated in Figure 5 which is drawn based upon normal equalizer strength as specified for military aircraft. It can be seen that a differential voltage of one-fourth volt is obtained on the generators yet to be connected when only five per cent load is on each of the connected machines. A differential voltage of one-half volt would require ten per cent load on each connected machine. In the appendix it is shown that the differential voltage is dependent only upon the per cent load on the connected machines, regardless of the number of generators associated with the system. These figures are based upon all voltage regulators being set alike. However, it can be said that with the differential relay set to close on at from 0.2 to 0.5 volt on a system of generators having equalizers on the voltage regulators of normal strength, if any generator fails to come on, it would not be able to furnish power to the bus under that load condition. Therefore, it might as well remain off until its voltage regulator setting is brought into line with the settings of other regulators on the system.

Another characteristic of the differential type of generator control relay has caused misunderstanding and that is the fact that it will not close a generator on to an unloaded bus because there is then no circuit for the differential coil. The existence of a very minute load or of batteries on the bus eliminates this. It is not a disadvantage because if there is no load to be supplied there is no use putting voltage on the bus. In testing these relays on a bench test, this has sometimes caused confusion where testing the relay against an open bus without batteries or load. Only a fraction of an ampere load is required to complete this circuit.

Flight Tests With Differential Generator Control Relays

In order to prove out these principles and to satisfy any who might be skeptical of the ability to close on, tests were made on a four-engined B-24 Liberator bombing plane equipped with differential relays and on the same plane equipped with voltage pickup type relays. The tests showed that either type of relay with proper adjustments was practical but that the differential type is superior. Also, the tests showed that with misadjustment of the voltage regulators, the voltage pickup type would chatter whereas the differential type did not. No trouble was encountered in bringing any generator on with differential-type relays. In fact, those who made the tests stated that with normal regulator settings, there would have been difficulty keeping them off the bus.

Tests were made and oscillograms taken for various settings of the regulators and various load conditions. Figure 6 shows the system elementary connections.

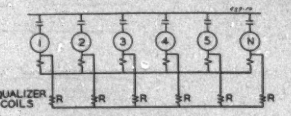


Figure 10. Schematic connection of equalizers on an N-machine system

These tests were purposely made severe by setting one regulator low and gradually raising its voltage setting. Figures 7 and 8 are oscillograms of these tests for the voltage-pickup and differential types, respectively. Note that Figure 7 shows a chattering condition whereas the same test with the differential relay, Figure 8, shows no chatter. Figure 9 shows a heavy load suddenly applied using differential relays with regulators set to prevent number 1 generator coming on until the application of the sudden load. It is to be noted that there was a sudden drop in bus voltage and a sudden rise in generator number 1 voltage and that generator number 1 came on within 0.05 second and carried its share of the load.

Conclusions

The differential-type generator control relay is superior to the voltage pickup type because it can be readily made to have a characteristic not subject to chatter even though the voltage regulators on generators operating in parallel do not have the same adjustment.

The voltage-pickup type of generator control relay can be made to function satisfactorily but is subject to chatter when regulators are not in adjustment on generators operating in parallel.

On a system including several generators operating in parallel, the differential type of generator control relay should give no trouble due to failure to close on the bus provided the voltage regulators are provided with equalizers of normal strength.

Less trouble with adjustment of pickup should be realized in service with the differential type than with the voltage-pickup type because a fairly wide tolerance in pickup differential voltage has a relatively minor effect on operation and will not result in chatter.

Appendix

It can be shown that for a given equalizer strength the differential voltage between machines on the bus and off the bus with all equalizer circuits closed is dependent only upon the percentage load on each connected machine. This is on the assumption that all equalizers and their leads have the same resistance and that all regulators hold constant voltage and are set for the same value except as influenced by the equalizers. Consider an N-machine system; see Figure 10.

The voltage applied to the equalizer circuit is determined by the load on the connected machines and the standard value is 0.5 volt for 100 per cent load. The effect of a given voltage applied to each equalizer coil is standardized. The United States Army value is a change of 2.5 volts for 0.25 volt applied to the equalizer coil of one regulator.

Let

R = resistance of equalizer coil and connected leads

N_i = number of machines on the bus

N_o = number of machines off the bus

L_i = per cent load current on each connected machine

Current in each equalizer of regulator with machine on the bus will be

$$\frac{L_i}{100}\times 0.5\times\frac{1}{N_i\left(\frac{R}{N_i}+\frac{R}{N_o}\right)}$$

Recalibration of each regulator with machine on the bus due to equalizer current is obtained by proportion as follows.

$$\frac{\frac{0.25}{R}}{\frac{L_i}{100}\times 0.5\times\frac{1}{N_i\left(\frac{R}{N_i}+\frac{R}{N_o}\right)}}=\frac{2.5}{\text{Volts recalibration}}$$

Volts recalibration below normal

$$=5\frac{L_i}{100}\frac{\frac{1}{N_i}}{\frac{1}{N_i}+\frac{1}{N_o}}$$

Current in each equalizer of regulators off the bus will be

$$\frac{L_i}{100}\times 0.5\times\frac{1}{N_o\left(\frac{R}{N_i}+\frac{R}{N_o}\right)}$$

Recalibration of each regulator with machine off the bus is obtained by proportion

$$\frac{\frac{0.25}{R}}{\frac{L_i}{100}\times 0.5\times\frac{1}{N_o\left(\frac{R}{N_i}+\frac{R}{N_o}\right)}}=\frac{2.5}{\text{Volts recalibration}}$$

Lighting Required for Commercial-Airline Aircraft

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LIGHTING plays as essential a role in the performance of a modern air-transport airplane as it traditionally does on the stage. It is the purpose of this paper to outline the extent of the subject and to acquaint the reader with the basic requirements of each of the specific applications. Actual airline operating experience will form the basis for these requirements.

The variety of problems involved in the lighting of a commercial airliner can be readily appreciated by referring to Figure 1. The percentage of the aircraft electric power supply which is required for the lighting of two representative sizes of aircraft is shown on Figure 2.

Exterior Lighting

Position Lights

In the application of lighting for navigation purposes, it is necessary that all aircraft conform to a standard arrangement so that there will be no confusion, with its unfortunate consequences. The Civil Aeronautics Administration has specified in their regulation CAR 15.20, *Position Lights*, the particular arrangement which an air carrier must employ. This system of position lighting is shown in Figures 3, 4, and 5.

With the advent of the war and increased aerial traffic, commercial-airline position lighting has undergone critical review. This survey in which the CAA, the Bureau of Standards, and the airlines collaborated consisted of installing additional lights on an airplane and flight testing. The flight tests were so conducted as to cover all the possibilities which might be encountered in air traffic. The most exacting condition of the flight test proved to be the one in which one airplane descended upon another ship flying against a background of multicolored city lights. The results of these tests indicated that a decided improvement could be gained by flashing the position lights in a uniform sequence. The immediate outcome of these tests was an amendment to the CAA regulations requiring all commercial aircraft to flash a red and white tail light alternately at a prescribed rate of 40 cycles a minute, each cycle to have the following characteristic: 150 degrees white, 10 degrees dark, 150 degrees red, 50 degrees dark. Both the red and white lights are to be fitted with 32-candlepower lamps. These red and white lights must conform in all other respects to the previous Civil Air Regulation. Permission was granted the airlines to flash all their position lights for a trial period. Figures 6 and 7 show the type of dual tail light and wing tip installations in use on a commercial airliner.

The airlines do not regard the present system of flashing lights to be the ultimate in position lighting and are acutely aware of the need for additional study of the problem. The following remarks are intended as a guide to this further study.

The existing CAR cutoff requirements effectively limit the maximum intensity of forward position lighting. If the intensity of the position light or group of lights as viewed from another airplane is considered to be a function of their relative approach velocity, then it is obvious that the maximum light intensity should be obtained when viewing the airplane from a head-on position, and this intensity should decrease in a reasonably uniform manner to an acceptable minimum when viewing the airplane from the rear. The problem of increasing the forward position-light intensity is complicated by the undesirable effect which any bright light located within the pilot's field of vision has upon his ability to discern external objects when flying through haze, light snow, or similar weather. In fact, the pilot need not be looking out of the airplane to be bothered by the flashing of a light reflecting from the haze.

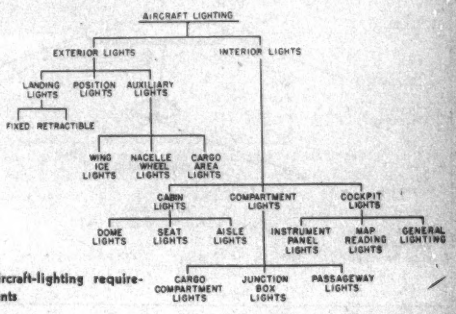

Figure 1. Airline aircraft-lighting requirements

Volts recalibration above normal

$$= 5\frac{L_1}{100} \times \frac{\frac{1}{N_0}}{\frac{1}{N_1}+\frac{1}{N_0}}$$

The sum of these two recalibrations is the differential voltage which is

$$\text{Differential voltage} = \frac{5 \times L_1}{100} = 0.05L_1$$

Thus for differential voltage of 0.2

$$L_1 = \frac{0.2}{0.05} = 4 \text{ per cent load}$$

For differential voltage of 0.5

$$L_1 = \frac{0.5}{0.05} = 10 \text{ per cent load}$$

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Figure 2. Relative power requirements of aircraft lighting equipment

these three phases of the landing, the airplane usually has three different attitudes with respect to the ground. With the fixed type of landing light which remains stationary relative to the airplane throughout the landing procedure, the illuminating effect of a beam pattern will vary with each of these phases. It is necessary that this beam pattern be so designed and the light suitably positioned

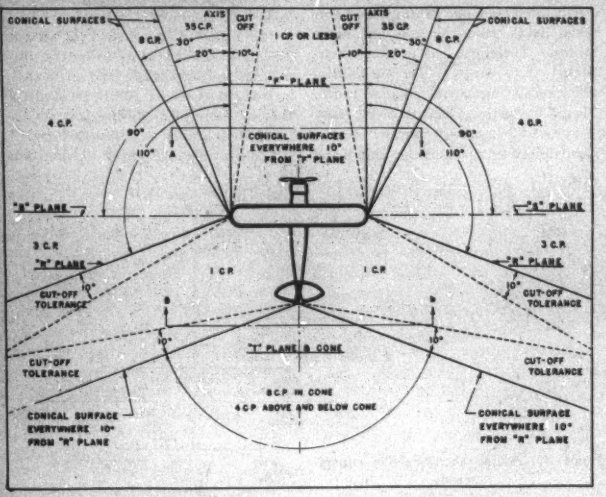

Figure 3. Angles and intensities of "airline forward" and "rear" position lights

It is also necessary to consider the effect of any position-lighting arrangement upon the passengers. Here again, the annoyance of a flashing light must be minimized, and the problem is complicated by the presence of polished wing surfaces.

New navigation-light fixtures should be designed so that the streamline of the airplane will be unaffected. It is most important that this streamline be kept inviolate as ice accumulation will not only reduce the utility of the lights, but will also seriously affect the aerodynamic efficiency of the wing.

Landing Lights

The general requirement for an aircraft landing light is that it furnish sufficient illumination in the area ahead of the airplane adequately to permit the pilot to guide the airplane to a safe landing. All three portions of a landing must be considered; namely, the approach to the field, the actual landing, and the subsequent taxiing to the parking space. During

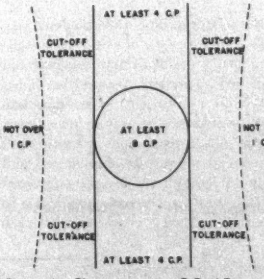

Figure 4. Showing section *B-B* of Figure 3

that sufficient illumination is obtained on the landing strip under all conditions.

There are in general three types of landing-light installations in use. The leading-edge-of-the-wing installation is the type most commonly used in commercial-airline aircraft (Figure 8). There are several disadvantages of this type of installation. The light lost by refraction through the curved lens is excessive, and the aerodynamic efficiency of the wing is affected. Furthermore, there is interference with the deicing of the leading edge of the wings. This type of installation is susceptible to damage from impact with objects such as birds with subsequent undesirable aerodynamic effects upon the airplane. The provision for bulb replacement is complicated by the necessity for installing sufficient fasteners on the hand-hole cover plates to meet the structural requirements for that portion of the airplane just aft of the leading edge of the wing. Consequently, the time required for a change of bulb is excessive.

The installation of the landing lights in the nose of the airplane, while not having the objections of interference with the deicing function or aerodynamic efficiency, does have a more objectionable effect of illuminating any haze or fog to such an extent as to interfere seriously with the pilot's vision from the cockpit.

A more recent type of landing-light installation is the retractable landing light (Figure 9). This light is usually mounted well under the wing and is controlled either hydraulically or by an electric motor. The bulb can either be illuminated automatically by means of a switch incorporated in the light assembly or can be illuminated in any position from the cockpit. The military services have standardized on the general requirements for electrically retractable landing lights for 12- and 24-volt d-c airplanes. The bulb is the sealed-beam type and is readily replaceable without the necessity of removing any wing structure. It is evident that this type of light does not have the objections common to the leading-edge and nose types; however, it has the objection of added mechanical complexity. This additional mechanism is another source of trouble, and should it fail to function satisfactorily, it will render the landing light inoperative. The Civil Aeronautics Administration, recognizing the various forms in which the landing-light installations might appear, has framed its requirements as follows.

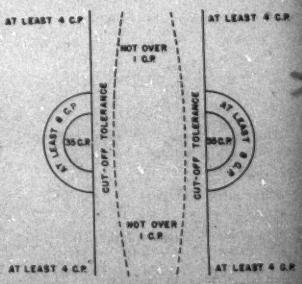

Figure 5. Showing section *A-A* of Figure 3

"Electric landing lights shall be so installed on multiengine aircraft that at least one should not be less than ten feet to the right or left of the first pilot's seat and be beyond the swept disk of the outermost propeller. On single-engine aircraft such lights shall be so installed that no visible portion of the swept disk of the propeller, if of the tractor type, is illuminated thereby. Individual switches for each light shall be provided in the pilots' compartment." It is a further CAA requirement that two lights be provided on any air carrier of passengers licensed for night flying.

To sum up the landing-light situation, present-day airplanes having the conventional tail-wheel type of landing gear do not provide suitable illumination for all three phases of airplane maneuvering involved in the landing. As a result the lights are adjusted so as to favor the illumination of the landing strip during the approach and landing position with the result that the light available for taxiing is very poor. It has been suggested that landing lights be furnished with double filaments similar to the type employed in automobiles so that taxiing might be accomplished under more favorable lighting conditions. Another solution to this problem would be properly to proportion the beam pattern from the landing light so that a sufficient amount of light is available at the various attitudes of the airplane. This can only be done, however, at the expense of the light intensity at any one working condition. In view of the compromises currently being accepted in regard to bulb life and lumens per watt output, it would be undesirable to adopt any system which does not fully utilize the lumen output of the lamps.

A problem of aircraft lighting which is seldom appreciated by anyone but the airline operator is the lamp burnout and replacement problem. This problem is particularly acute for the position and landing lights for the following reasons. An air carrier for passengers cannot be given flight clearance without the full compliment of position and landing lights as specified by the CAA. Landing lights, which are lighted just prior to the aircraft's departure from the loading ramp, and in some cases not until the aircraft is ready for take-off, usually fail when the lamp is switched on. In the case of both the position lights and the landing lights the transition, from the airplane's condition at rest with engines not running to the excessive vibration experienced when engines are being ground run and the airplane is taxiing, is sufficient to produce failure in a bulb which has approached the end of its service life. In most cases, therefore, the light-bulb failures occur at the most critical time and result in what is known as a station delay or an interrupted flight. These delays or interrupted flights are the "headaches" of airline operation.

Considering the life expectancy characteristic of the incandescent lamp, the best that one can hope for, if a periodic replacement program is put into effect, is to reduce percentagewise the number of delays and interruptions. This procedure can never eliminate them. The economy of such a program must be balanced against the intangible cost of a delay or interrupted flight. A possible solution of this difficulty for the position lights is the use of lamps having double filaments of different structural characteristics so as to provide a lamp for which only one filament would burn out at a time. This would have the advantage of providing a light of reduced intensity in case the burnout of one of the filaments occurred in flight. It is obvious that such a system could not be applied to the landing-light bulb.

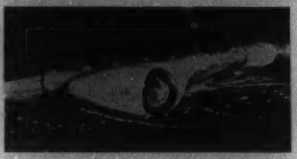

Figure 7. Installation of approved type of wing-tip position light

Figure 8. Leading-edge-of-the-wing type of landing light

Auxiliary Lights

In addition to the position and landing lights various other auxiliary lights for lighting some portion of the aircraft exterior are being used. The pilot's desire to see the leading edge of the wing at night during icing conditions has resulted in the installation of lights in either the fuselage or the outboard nacelles which floodlight the leading edges of the wings. Lights which are being used for this purpose are the type manufactured as automobile spotlights. These lights are provided with refracting lenses to provide the particular light pattern required for even distribution along the entire length of the wing. The installation of these lights has met with the approval of the CAA. They are satisfying a need which will exist until more positive and automatic wing deicing equipment is available. It is interesting to note that these wing ice lights are also used as an aid to taxiing on the ground.

Lights have been installed inside of the engine nacelles which house the landing gear in order to floodlight the gear so that the pilot may check its position in flight at night. The installation of lights adjacent to the cargo doors has been proposed so as to provide sufficient illumination for cargo handling.

Interior Lighting

Cabin Lighting

The problem of cabin lighting in a commercial airliner is quite similar to that of

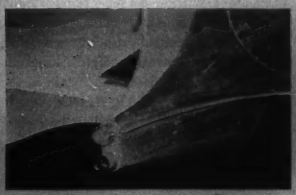

Figure 6. Dual flashing taillight installation

Figure 9. Under-the-wing-type hydraulically retractable landing light

Figure 10. Cabin dome-light installation in a DC-3 airplane

Figure 11. Combination dome light and ventilator outlet—Douglas DC-4 airplane

the modern deluxe coach or railway car. Generally speaking, it is necessary to provide two types of illumination; namely general lighting and individual-seat lighting. The general illumination for cabins commonly consists of a number of dome-light fixtures extending along the center of the cabin ceiling and suitably spaced to provide a uniform intensity of illumination at the seat level (Figure 10). These dome-like fixtures usually consist of one or two incandescent light bulbs of 21 to 32 candlepower, each covered by a diffusing light cover made of glass or a lighter plastic equivalent. Care must be taken in the selection of the plastic compound for this purpose inasmuch as the limited space provided for the bulbs results in fairly high temperatures. The usual thermoplastic materials will sag and warp and eventually present a very unattractive appearance. Figure 11 illustrates a Douglas Aircraft Company design which places the light inside of a ventilation duct thereby obtaining better cooling of the lamp enclosure.

Some means must be provided for lowering the intensity of the dome lights during night flight so that passengers desiring to sleep will not be annoyed. The dimmed lights must provide enough illumination for the stewardess or passenger who may desire to move about the airplane. A better solution of this problem is the installation of aisle lights which may be turned on when the dome lights are extinguished. In this manner the illumination is applied where it is needed with a minimum of discomfort to reclining passengers. The aisle lights are commonly installed at the base of the individual seats and so positioned that a uniform lighting of the aisle is obtained.

A particular problem of cabin lighting at night exists at the vicinity of the main cabin door where passengers leaving or boarding the airplane must be checked in and out by the stewardess. Since it is not customary to wall off that section of the cabin containing the seats from the entrance door, the light in the vicinity of the door must be so designed that its cutoff in the forward direction will not permit it to strike the rearmost reclining-passengers' heads. Furthermore, the brightness of the light-cover glass must be kept to a minimum when observed from the rearmost seat. While it is obvious that these

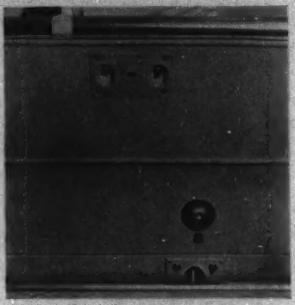

Figure 12. Individual seat light installations—Douglas DC-3 airplane

requirements may be simply satisfied by some sort of shade, the height of the cabin ceiling and the undesirability of installing any projecting surfaces make this method of solution impractical.

The basic requirement of the individual seat light is that it illuminate the normal reading area in front of the passenger without annoyance to any other passengers. The normal positions and movements of adjacent passengers should not interfere with the light supplied to the seat for which it is intended. Individual-seat-light installations usually take the form of an incandescent lamp totally enclosed in a metal box with the exception of a small opening suitably designed to provide the required beam pattern (Figure 12). The switches for controlling these lights must be easily reached from their respective passenger seats. The use of lenses for the purpose of improving the efficiency of the lighting system is impractical from the maintenance viewpoint inasmuch as the type and focal length necessary for this application requires the maintenance of close tolerances between these two parts. Furthermore, the use of lenses presents an additional cleaning problem.

The individual lighting installation is further complicated on airplanes with sleeping accommodations inasmuch as suitable lighting must be provided in the upper berths. The problem of interference is minimized inasmuch as the individual compartments are partitioned or curtained; however, care must be taken that upper and lower berth lights in the same compartment do not provide stray illumination to one another.

In addition to the general cabin lighting, there are various compartments requiring lighting; namely, dressing rooms, toilets, coat closets, and buffets. Each of these compartments presents its particular problems. The general type of dome light is usually employed with the exception of the dressing rooms where additional lights are provided adjacent to the mirrors (Figure 13).

Up to the present time fluorescent cabin lighting has not made its appearance in the commercial airplane. In view of the above requirements, it appears that an application exists for the fluorescent type of lighting for supplying general cabin and compartment illumination. In the application of fluorescent lighting to aircraft, the following factors must be evaluated:

1. What will be the difference in weight over that of an incandescent bulb type of installation providing the same level of illumination?
2. How will the service life and cost of operation compare with the existing system of incandescent lighting?
3. Does the improved appearance of the fluorescent type of installation warrant penalties to be taken on either the weight or maintenance items?

Cockpit Lighting

If one were to ask what the most important lighting application is in an airplane, the answer would be universal in its agreement on the instrument panel lighting. The importance of proper panel lighting and its contribution to the safe operation of the airplane has long been recognized and a number of different types of lighting systems developed.

The general problem of instrument-panel lighting can be stated as the application of a controlled, uniform intensity of shadowless illumination over all instrument dials which must be observed by the pilot during the routine operation of the airplane. Furthermore, this illumination must be so accomplished that there are no extraneous reflections of light visible to the pilots from instrument cover glasses, windshields, or other reflecting surfaces. The instrument-lights' function has been similarly described by the CAA in their regulation CAR 04.5826 which reads, "Instrument lights shall be so installed as to provide sufficient illumination to make all flight instruments easily readable and shall be equipped with rheostat control for diming unless it can be shown that a nondimming light is satisfactory."

There are in general three types of instrument-light installations. They are:

1. Incandescent bulb floodlighting of the instrument panel.

2. Individual (built in) ring lights on each instrument.

3. Fluorescent floodlighting of the instrument panel.

Each of the above methods has its advantages and disadvantages of which the following are the more important. In floodlighting the panel by incandescent light bulbs, the following problems are outstanding:

1. Reflections from instrument cover glasses and windshields.

2. Even distribution and shadowless illumination of all the instruments.

3. The difficulty of locating the various lighting fixtures in the airplane to accomplish the first two objects.

The individual ring lighting of instruments solves the problem of extraneous reflections and of securing uniform and shadowless illumination. However, the chief disadvantage of this type of lighting is the penalty which must be taken in the installation as each instrument must have a wire connection, and these wires must be located in back of the instrument panel which is one of the more congested spots on the airplane.

The use of fluorescent lights for instrument lighting has been given considerable impetus by the military services for whom the dark-cockpit type of night flying is an absolute necessity because of tactical reasons. The principle of fluorescent lighting has been widely demonstrated to the general public by theaters which have used this medium for staging spectacular costume changes. It is based upon the action of near-ultraviolet radiation on fluorescent paints. The wave length of this radiation is in the band from 3,000 to 4,000 angstroms and consequently has no detrimental effect to the eyes or skin. The efficiency of the fluorescent lamp is approximately two to three times that of the equivalent wattage of incandescent lamp. The history of the instrument-panel fluorescent lighting goes back to the year 1934 when an installation of a cold-cathode argon lamp was used with a cobalt-blue glass filter to flood the instrument panel with near-ultraviolet radiation (Figure 14). The instruments were coated with a radium base paint which reacted quite readily to these lights and produced a legible instrument indication without any extraneous illumination. The limitations of the argon lamp as a source of ultraviolet light became apparent as the size of instrument panels and the distance which these lights had to be mounted from it became greater.

A series of 4- and 6-watt 118-volt a-c fluorescent lamps were designed in conjunction with the United States Army Air Corps, who pioneered in their development. The design of these lamps is unique in that they contain a fluorescent coating on the inside of the glass envelope which transposes the ultraviolet radiation

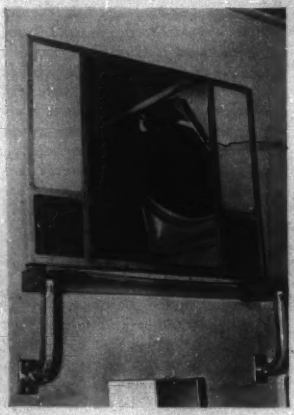

Figure 13. Mirror lights—Douglas DC-4 airplane

of the ionized mercury-vapor gas into both visible and near-ultraviolet radiation. The lamp is provided with a rotable shutter and a blue glass filter which permits some control in the amount of near-ultraviolet radiation output and permits the use of visible light for reading of maps and charts in the cockpit. These lamps require a power source of 118 volts for their operation as well as a reactor (ballast) and a starting switch similar to that employed in the commercial fluorescent lighting equipment.

Within the past year a 24-volt d-c mercury-vapor bulb has been made available. The same basic principles apply with the exception of the size and shape of the bulb which resembles an automobile headlight lamp and is enclosed in a fixture provided with a slotted face for permitting either dark lighting or visible lighting of the instrument panel. The use of the 24-volt lamps in aircraft having 24-volt d-c electrical systems has abolished the need for inverters formerly required for the 118-volt equipment.

In conjunction with the design of the fluorescent lighting equipment just described, the military services have sponsored the use of fluorescent-paint

Figure 14. Instrument-panel light installation —DC-3 airplane

materials which are activated by the near-ultraviolet radiation but which extinguish immediately upon removal of the radiation. The development of fluorescent-paint material has progressed to the stage where a wide range of colors are available which will fluoresce with approximately the same color as they appear in daylight. This property is advantageous in order to preserve the utility of the instrument limit markers used to designate various safe minimum and maximum values of engine pressures, temperatures, and airspeed.

Independent studies made by a number of physiologists have demonstrated that the ideal color for instrument illumination is in the red spectrum, the reason being that the red waveleng hs have very little effect upon the dark-adapted eye. As a result of these findings, incandescent-light fixtures have been equipped with red glass filters for floodlighting panels with red light for night flying where a minimum of interference with the pilot's ability to discern objects through the windshield is required.

As in most lighting applications, particularly those involving colored lights, the personal element is an important factor. As an example, one can cite the attitude of the commercial airline pilots to the argon lighting system which has been in use for the past nine years. There are about as many pilots who do not use this form of lighting because they personally do not like it as there are pilots who would not be without it. The same reactions have been recorded by the physiologists who have noted the personal opinions of the various subjects testing the red-light installation. Much to the surprise of some of these subjects, the tests showed that while they disliked the colored lighting, their visual ability to see objects out of the cockpit had been improved over their previous ability with their customary and preferred type of illumination.

Some form of glareless general cockpit

illumination is necessary in addition to various spotlights provided for illuminating the pilot's controls, switches, valves, etc. It is common practice for most pilots to fly with a brightly lighted cockpit when cruising on flights of long duration. Apparently this practice has been found less fatiguing than flying with a darkened cockpit with only localized lighting for illumination. The ability to flood the cockpit with general illumination is a desirable safety measure when flying through thunderstorms in the presence of lightning. It has been determined from a number of recorded cases in which pilots were momentarily blinded by lightning flashes that the duration of their disability was generally related to the intensity of cockpit illumination prior to the discharge.

In addition to the problem of illuminating the instrument panel for the pilots, there is the problem of satisfactorily illuminating the work areas for the flight engineer, navigator, and radio man in the larger airplanes having provisions for such personnel. The lighting provisions for each of these crew members usually require the illumination of an auxiliary instrument panel mounted in front of the observer plus a local spotlight for illuminating his table area. All lighting for the individual crew member must be carefully arranged so as not to interfere with the other crew members. The various lighted work areas of the nonpiloting crew members must be shielded from the pilots' compartment and it is customary to drape a curtain between the pilots and the remainder of the flight-crew compartment. It is also necessary to provide a suitable light shield for the navigator's use when sighting through the ship's astrodome. In general, the location of the various light sources and curtains must be determined from a full-scale mock-up of the crew compartment. It is essential that the installation of all glass reflecting surfaces be duplicated in the construction of the mock-up. Only in this manner can the multiple reflections obtained from these windows be detected and eliminated.

Conclusion

The problems associated with the lighting of a commercial transport airplane are many and varied, and current practice leaves much to be desired. Generally speaking, there is need for the development of colored position-light sources of greater intensity and better efficiency. Such developments should seek a reduction in size and weight of the installation and be designed to fit more closely the aerodynamic streamline of the airplane.

In the field of aircraft landing lights the development of a light which will meet all the requirements associated with the landing and ground running of the airplane without increasing the weight of the installation is needed. The present life of the position light and particularly the landing-light bulb is exacting too great a penalty from the airline operator in view of the coincidence of lamp failures with the time of aircraft departure.

Perhaps the greatest immediate change which can be expected in the post war commercial airliner will be in the realm of cabin lighting. This opinion is based upon the unexploited application of fluorescent lighting to aircraft cabin interiors. Light installations of more pleasing appearance and producing a higher intensity of illumination for the individual passenger at less cost in weight and energy are needed.

The flight crew personnel can look forward to improved cockpit lighting installations as a result of the experience which is constantly being accrued by the military services in the laboratory as well as in the field.

No paper on aircraft lighting would be complete without due acknowledgement to those agencies which are actively engaged in furthering commercial aircraft lighting developments. These are the aircraft lighting committee of the Air Transport Association, the committee on aviation lighting of the Illuminating Engineering Society, the technical development division of the Civil Aeronautics Administration, and the United States Bureau of Standards. These agencies are mutually co-operative and will provide the necessary guiding hand to the future development of commercial aircraft lighting.

Fusing Practices on Distribution Systems—II

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A PAPER on fusing practices on distribution systems operating at five kilovolts and below was presented at the winter technical meeting.[1] It discussed the results of a questionnaire which had been submitted to about 200 operating companies and presented the data in graphical form. The data of the present paper were gathered on systems operating between 5 and 15 kv. Wherever possible, the form of the previous paper has been followed in order to permit ready comparison.

Distribution Transformer Fusing

In answer to the question, "Why do you fuse distribution transformers?" it was found that 86 per cent of the companies fuse to protect the system from the transformer, 61 per cent fuse to protect the transformer, 18 per cent fuse to indicate the location of faults, and 17 per cent fuse as an isolating means. The total of these percentages is more than 100 per cent, because several companies expect the fuse cutouts to perform more than one function.

The primary windings of distribution transformers are fused by the use of enclosed indicating cutouts by 34 per cent of the companies. The enclosed nonindicating cutout is preferred by 12 per cent of the companies, and 54 per cent expressed a preference for the open dropout type. Perhaps the large preference for the open type is caused by the fact that the insulation is such as to put a grounded mounting bracket between the terminals of the fuse. At this higher voltage the dropout feature is almost a necessity in order to prevent voltage from appearing across exposed organic insulation of a blown fuse.

The use of repeating fused cutouts on distribution transformers is very limited. This probably is brought about by the relatively high cost of this type of cutout and by the fact that almost all internal transformer faults are of a permanent nature. However, nine per cent of the companies reported some use of repeating cutouts for transformer fusing. This agrees with the eight per cent found on systems below five kilovolts.

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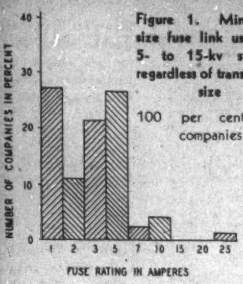

Figure 1. Minimum-size fuse link used on 5- to 15-kv systems regardless of transformer size

100 per cent = 104 companies

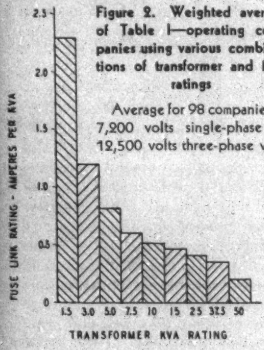

Figure 2. Weighted average of Table I—operating companies using various combinations of transformer and fuse ratings

Average for 98 companies 7,200 volts single-phase or 12,500 volts three-phase wye

As in the previous questionnaire, the companies were asked the extent of the use of cutouts at locations where the short-circuit current exceeds the published interrupting rating. It was found that the policy of 37 per cent of the companies is to use cutouts at locations where the published interrupting ratings might be exceeded.

Transformer Fuse Ratings

The rating of the primary fuse which is chosen for a distribution transformer is usually correlated with the kilovolt-ampere rating of the transformer. In the case of smaller transformers, usually below five kilovolt-amperes, other factors predominate. Consequently, the question was asked as to the minimum-size fuse link used on the system and the factors controlling its choice. The three factors most frequently mentioned in the order of their predominance were mechanical strength, lightning, and transformer rating. Figure 1 illustrates the practice as to minimum fuse rating and shows graphically the number of companies in per cent using a given size. The range of values is about the same as that found for lower-voltage systems except that a larger number use the one-ampere link.

Table I is a transformer fusing chart showing the percentage of operating companies using the various combinations of transformer and fuse ratings. The most popular link for each transformer rating has been pointed out by the bold-faced type in the table. This table applies to 6,600–7,600-volt single-phase systems and 11,000 to 13,800 volts three-phase wye systems. It is interesting to note that the plurality of customers use a five-ampere link as a minimum size for all transformers up to 15 kva. A weighted average of Table I is graphically presented in Figure 2 which shows the fuse link rating in amperes per kilovolt-ampere plotted against the transformer kilovolt-ampere rating. It will be noted that the fusing ratio varies widely, a much higher fusing ratio being used for the smaller transformers. The data in Table I have been plotted again in Figure 3. This table shows the number of companies in per cent using a given fusing ratio, the fusing ratio being the link rating divided by the full-load current of the transformer. The data show even less uniformity in fusing practice than is found for transformers operating below five kilovolts.

Table II applies to systems operating at voltages ranging from 6,600 to 7,600 volts three-phase delta. Three-phase wye systems from 6,600 to 7,600 volts are shown in Table III. Single-phase systems operating between 11,000 and 13,800 volts are found in Table IV. Table V applies to systems operating in three-phase delta between 11,000 and 13,800

Table I. Operating Companies Using Various Combinations of Transformer and Fuse Rating

7,200 Volts Single-Phase or 12,500 Volts Three-Phase Wye
100 Per Cent = 98 Companies

Single-Phase Transformer Rating—Kva (Multiply by 3 for Bank Kva)	Fuse Link Rating—Amperes										
	1	2	3	5	7	10	15	20	25	30	40
	Number of Companies in Per Cent										
1.5	22.8		17		19.3	35.3		1.1		4.5	
3	20.0		14.4		20.0	40.0		1.1		4.5	
5	5.3		8.5		31.9	44.7		2.1		7.5	
7.5	3.0		8.0		23.0	46.0		7.0		13.0	
10			7.1		28.6	42.8		8.6		14.3	
15			2.2		4.3	55.4		8.7		17.4	
25					2.1	8.3		24.7		42.2	
37.5						2.2		3.3		42.4	
50								1.6		14.8	

Single-Phase Transformer Rating—Kva (Multiply by 3 for Bank Kva)	Fuse Link Rating—Amperes													
	1	2	3	5	7	10	15	20	25	30	40	50	65	
	Number of Companies in Per Cent													
1.5		3.9		11.5		42.3		34.6			7.7			
3		3.6		3.6		28.5		53.5		3.6	7.2			
5				3.0		18.2		42.5		21.2	12.1	3.0		
7.5				3.2		3.2		35.6		6.5	29.0	19.3	3.2	
10								16.1			42.0	16.1	16.1	9.7
15								3.0		6.1	30.3	18.2	21.2	9.1 12.1
25											19.4	16.1	12.9	12.9 12.9 12.9
37.5												20.0	20.0	6.7 13.3 16.7 3.3 3.3

Table III. Operating Companies Using Various Combinations of Transformer and Fuse Rating

7,200 Volts Three-Phase Wye; 100 Per Cent = 21 Companies

Single-Phase Transformer Rating—Kva (Multiply by 3 for Bank Kva)	Fuse Link Rating—Amperes												
	1	2	3	5	7	10	15	20	25	30	40	50	65
	Number of Companies in Per Cent												
1.5	7.1		14.3		26.6		37.7		7.2		7.1		
3	7.1				28.6		57.2		7.1				
5	6.3					62.3		18.9		12.5			
7.5					6.3		50.0		18.7		18.7	6.3	
10					6.2		31.3		6.2		31.3	25.0	
15							14.3				28.6	42.8	9.5 3.8
25											40.0	13.3	20.0 20.0
37.5											26.6	6.7	13.3 6.7 26.6 6.7 6.7 6.7

volts. The data of Tables II through V could be shown in graphic form as was Table I in Figures 2 and 3 and would show the same general trend.

All companies replying use primary fused cutouts. Reference to Figure 3 will show that the fusing ratios are such that in many cases low-impedance secondary faults near the transformers will be cleared by the primary fuses. However, secondary fuses are used by 18 per cent of the companies, as contrasted with 12 per cent for systems operating below five kilovolts.

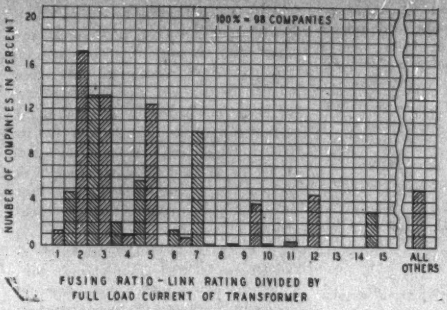
100% = 98 COMPANIES
NUMBER OF COMPANIES IN PERCENT
0
4
8
12
16
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
ALL OTHERS
FUSING RATIO - LINK RATING DIVIDED BY FULL LOAD CURRENT OF TRANSFORMER

Figure 3. Weighted average fusing ratio for all ratings of transformers plotted from data of Table I

Line Sectionalizing

It was found that 88 per cent of the companies make use of fused cutouts for line sectionalizing. Of these, 66 per cent use them on the main feeders, 87 per cent on the three-phase branch feeders and 95 per cent on single-phase laterals. The repeating cutout is most frequently found on the main feeder where 67 per cent are of this type. The three-phase branches are fused by repeating cutouts in 52 per cent of the cases, and this figure drops to 39 per cent on single-phase laterals. About 74 per cent of all cutouts used for line sectionalizing are of the open type. This contrasts sharply with the practice found on systems operating below five kilovolts, where 70 per cent are of the enclosed type. The rather wide variation in fusing practice for line sectionalizing is illustrated by Figure 4. This shows the number of companies in per cent using a given number of line-sectionalizing fuses in series. This figure shows that 63 per cent of the companies consider the use of more than three sectionalizing fuses in series to be impractical.

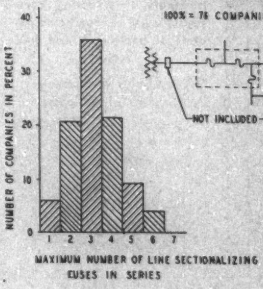

Figure 4 (below). Line-sectionalizing practice employed by 76 companies

Conclusions

In general, the data applying to systems above five kilovolts agree closely with those for systems below five kilovolts. Perhaps one reason for this is the fact that the same companies were questioned in each case. There are a few discrepancies, such as the preference for open cutouts at the higher voltage, and these are easily understood from a consideration of the factors involved. There appears to be a trend towards larger fuse sizes for use with distribution transformers, which the authors consider to be very desirable. The high percentage of the repeating fuses for sectionalizing service is indicative of a trend toward automatic reclosing, but it is the authors' belief that the small reclosing breaker eventually will supplant repeating fuses for line protection.

Discussion with operating engineers reveals that many have come to the conclusion that the use of larger fuse links leads to reduced operating expense without any actual increase in the rate of transformer failure. The larger link while reducing unnecessary outages does not change appreciably the time required to disconnect a faulted transformer from the circuit. As no fuse link can give adequate thermal protection to a transformer, little if anything is lost by employing larger links. It is hoped that further study of this problem will lead to additional operating data which will allow quantitative interpretation of the merit of increasing the size of fuse link used on transformers.

Table IV. Operating Companies Using Various Combinations of Transformer and Fuse Rating

13,200 Volts Single-Phase; 100 Per Cent = 44 Companies

Single-Phase Transformer Rating—Kva	Fuse Link Rating—Amperes								
	1	2	3	5	7	10	15	20	25
	Number of Companies in Per Cent								
1.5	22.6	9.1	9.1	41.0		18.2			
3	33.4	12.1	9.1	30.3	3.0	12.1			
5	34.1	9.1	20.4	25.0	2.3	9.1			
7.5	9.8	24.4	19.5	34.1	2.4	9.8			
10	7.1	7.1	21.5	21.5	7.1	35.7			
15		11.4	31.8	45.4	6.8	4.6			
25		5.0	12.5	50.0	12.5	17.5		2.5	
37.5			4.9	31.7	17.1	34.2	7.3	2.4	2.4
50				9.8	7.3	48.8	24.4	7.3	2.4

Table V. Operating Companies Using Various Combinations of Transformer and Fuse Rating

13,200 Volts Three-Phase Delta; 100 Per Cent = 36 Companies

Single-Phase Transformer Rating—Kva (Multiply by 3 for Bank Kva)	Fuse Link Rating—Amperes												
	1	2	3	5	7	10	15	20	25	30	40	50	65
	Number of Companies in Per Cent												
1.5	15.4	11.5	23.1	46.2	3.8								
3	6.5	9.7	25.8	51.5	6.5								
5	3.0	6.1	21.2	45.4	18.2	6.1							
7.5		5.6	5.6	50.0	11.0	25.0			2.8				
10		3.2	3.2	25.9	16.1	19.3	25.9	3.2	3.2				
15			2.8	27.7	5.6	22.3	22.2	16.7	2.8				
25				2.9	5.9	38.3	5.9	17.6	14.7	11.8		2.9	
37.5					8.6	17.1	22.9	17.1	5.7	11.4	11.4	2.9	2.9

Reference

1. Fusing Practice on Distribution Systems —I. John S. Parsons, J. M. Wallace. AIEE Transactions, volume 63, 1944, March section, pages 89–91.

Electronic Regulator for Arc Furnaces

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Synopsis: With the increased use of arc furnaces in the production of alloy steel, new interest has been aroused in both old and new methods of automatic regulation of electrode position. The regulator described in this paper is an electronic type which controls electrode position as determined by response to current in the electrode and voltage between the electrode and the furnace shell. Features and performance of an installation for a furnace having hydraulic control are illustrated.

THE power input to arc furnaces has always been controlled by automatic adjustment of electrode position. Figure 1a shows a typical installation of an arc furnace which employs hydraulic electrode positioning. In this type of furnace air up-push is used to counterbalance the weight of the electrode arm. Hydraulic means, controlled by a small motor, is employed to lower or raise the arm.

In the operation of the furnace, electrode adjustment is necessary because, as the charge melts down, the electrode must be lowered to maintain the arc. The scrap, as it melts, frequently falls against the electrodes, causing a short circuit and making withdrawal necessary. Adjustment of the electrodes is also necessary to allow for normal consumption of the graphite of which they are made.

Early methods of arc-furnace control consisted of simple current-operated devices. The electrode current in each phase was supplied from a current transformer to the coil of the regulator element. The pull of the coil was then balanced against a spring and the operation of the regulator contacts caused the electrode motor contactors to close the motor armature circuit in a manner to either raise or lower the electrode as the current deviated from a predetermined value. This method of regulation was found generally unsatisfactory, chiefly because the restraining force of the spring had a constant value and other factors were not taken into account.

A better method was then developed using another coil in place of the spring. Across this coil was impressed the arc voltage. As is well known, the voltage drop across the arc will increase as the current is decreased and vice versa. It can be readily understood that, when the varying pull of the coil or other regulating device which is proportional to the electrode current is balanced against a restraining force which is proportional to the arc voltage, the utmost sensitivity to changes in arc length is obtained in the regulator.

This principle of regulation has been in use for a period of about 15 years and has proved the best so far devised. For further improvement it seemed necessary to look to the actual control of voltage impressed across the electrode control motors, which for many years has been a constant potential d-c reversing control combined with dynamic braking. Figure 1b shows a view of the electrode motors used for controlling the electrodes of the arc furnace shown in Figure 1a. The motor in this case is one-half-horsepower frame size.

Quite recently electronic motor control has been developed and has proved successful on many applications where wide range of speed control and quick response is desired. It is possible to obtain many combinations of acceleration and speed range with a minimum of apparatus and almost instantaneous response. The means for varying motor speed is different from the older method of varying the field of the motor and holding a constant potential on the armature. Instead, the field is held constant and the armature voltage is varied to give the desired speed. The use of electronic regulation and control of the type described in this paper, for electrode motors, eliminates moving parts in the electrical equipment up to the motor. At the same time it provides the necessary sensitivity and high speed of response.

The electronic regulator includes a number of electronic tubes which take the place of relays and contactors to control the input to the furnace electrode motors. The power supplied to the regulator is taken from the available a-c line and no direct voltage is required from any separate source. The grid to cathode circuit of the vacuum tubes constitutes the input of the device, while the output is obtained from the thyratron-tube circuit. The principal grid voltages for the vacuum regulating tube include:

1. A control voltage which serves as a reference against which the quantity to be regulated is compared.
2. A control voltage which is proportional to the quantity to be regulated.
3. A self-biasing voltage connected in series with the cathode.

For a high degree of accuracy, the various grid voltages should have complete control over the regulating tube without causing the tube to saturate

Figure 1a. Typical arc furnace having electrodes arranged for hydraulic positioning

Figure 1b. Electrode control motors for the furnace shown in Figure 1a

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J. E. REILLY and C. E. VALENTINE are with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

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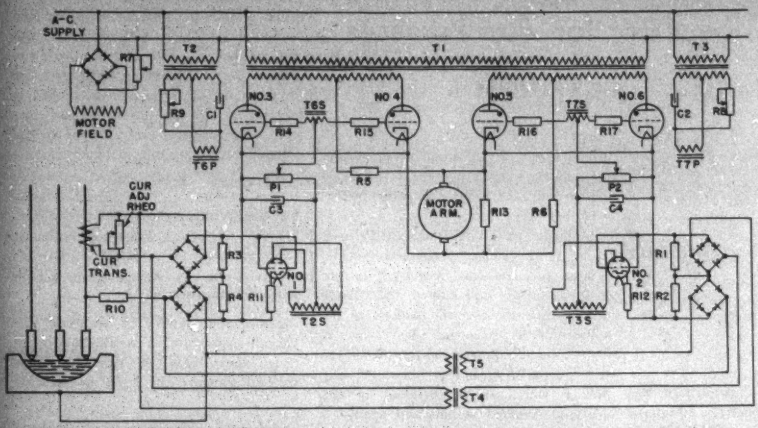

Figure 2. Simplified schematic diagram of arc-furnace regulating system

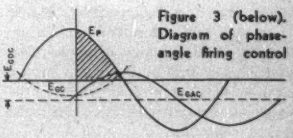

Figure 3 (below). Diagram of phase-angle firing control

because of the grid swinging positive. The self-biasing resistor is designed so that the regulating tube will be working along the straight line of its saturation curve similar to that of a class *A* amplifier. This results in a high degree of amplification since an extremely small change of the grid voltage is ample to change the output of the regulating tube over a wide range.

The speed of response of this type of regulating element is almost instantaneous. There is practically a complete absence of any retarding quantity such as inductance which might delay changes of current flow within the element.

Figure 2 shows an elementary schematic diagram of the regulating system. To simplify the diagram, certain details including grid balancing circuits, have been omitted. The grid control voltage of the regulating tubes, proportional to the electrode current, is taken from two Rectox rectifiers, which are connected to a current transformer in the electrode circuit. The grid control voltage, proportional to the arc potential, is taken in a similar manner from the voltage between each electrode and the shell of the furnace. In practice, when the furnace transformer breaker is closed, voltage is applied to the potential circuit which causes the output of tube number 1 to decrease. This in turn decreases the drop across potentiometer *P*1, supplying negative grid direct voltage to tubes numbers 3 and 4. When the negative grid voltage is decreased, tubes numbers 3 and 4 break down and start conducting, supplying full-wave rectified voltage to the electrode motor in the direction to lower the electrodes.

When the first electrode strikes the metal, the voltage drops to zero causing the voltage to be removed from the potential circuit, thereby allowing tube number 1 to increase its output, consequently increasing the negative grid voltage on tubes numbers 4 and 5, thereby blocking the conduction of current through these tubes. When a second electrode strikes the metal, current flows causing a voltage to appear in the current circuit which will place a negative grid voltage on tube number 2, thereby decreasing its output. Tubes numbers 2, 5, and 6 and potentiometer *P*2 will operate in the same manner as tubes numbers 1, 3, and 4 and potentiometer *P*1 did for the lowering operation. A voltage will then be impressed on the armature circuit in the direction to raise the electrodes thus establishing an arc. As the arc is lengthened, its voltage increases and the current decreases until a balance is established between the potential and current grid control voltages. The third electrode is controlled in a similar manner.

As the charge melts and flows down, or as the electrodes burn off, or the scrap falls against the electrodes, the balance between the control grid voltages is continually being disturbed. When this takes place, the two regulating tubes change the voltage output from the thyratron tubes that supply the electrode-motor armature power.

The variable voltage for the motors is obtained by superimposing an alternating voltage wave on the grid direct voltage of the main thyratron tubes. By displacing the a-c wave 90 degrees lag with respect to the thyratron anode voltage, the a-c wave will cut the critical grid voltage line at different points as shown by Figure 3, as the direct grid voltage of the power tubes is either raised or lowered. This allows the thyratron to conduct for varying portions of the half cycle.

A wide range of current adjustment is obtained by means of a rheostat shunting

Figure 4. Metal-enclosed electronic regulator unit

the current transformer. This method is used since it maintains the same sensitivity for all current settings.

Provision is made for controlling the electrodes manually, either individually or in a group. This facilitates handling of the electrodes during charging, pouring, and changing electrodes.

Figure 4 shows a front-view arrangement of the regulating equipment in a single metal-enclosed unit. A hinged panel door is used on the front of the regulator cabinet to permit access to various tubes and their connections. A bolted rear plate is provided in two sections so that any one or all of the regulator panels can be readily removed. The control panel is arranged for setting into the wall of the furnace vault in the usual manner.

The equipment is made so far as possible in one unit so that the various parts can be protected from dirt and physical damage. This also permits factory assembly and complete test, up to the operation of the electrode motors. A minimum of external connections and erection time is thus required.

Figure 5 is an oscillogram showing typical operation of the furnace during the melt-down period. This demonstrates the high speed of the electrode. Unsustained sudden variations in current cause no extra action of the equipment, but sustained changes cause immediate response. It will be noted that the electrode is withdrawn at relatively high speed when a cave-in takes place.

The start of the picture shows the electrode in comparatively stable operation, then suddenly the arc current is stopped indicating the arc has been broken. Instantly voltage is applied to the electrode motor to lower the electrode and re-establish the arc. Contact is made and the arc is drawn out until the arc voltage and current are returned to the desired quantities. The film shows this operation to have taken place in approximately 19 cycles. It should be appreciated that during the melt-down period, electrical conditions change rapidly, necessitating more or less continual electrode movement.

Figure 6 is an oscillogram showing performance during a portion of the refining period. Here relatively small changes in current take place and consequently only small movement of electrodes is required. Because of the inertia of the motors and electrodes, sudden-unsustained variations do not cause movement of the electrodes.

Figure 7 shows a high-speed oscillogram taken during the refining period. This

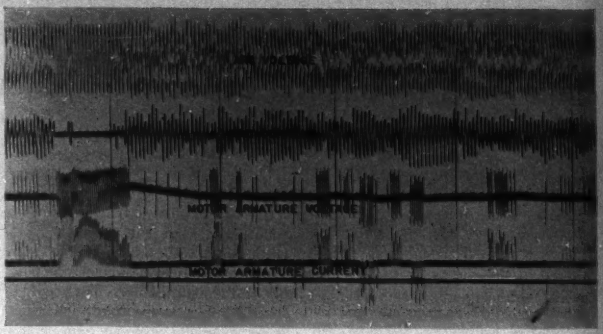

Figure 5. Oscillogram showing electrical performance of regulator during melt-down period

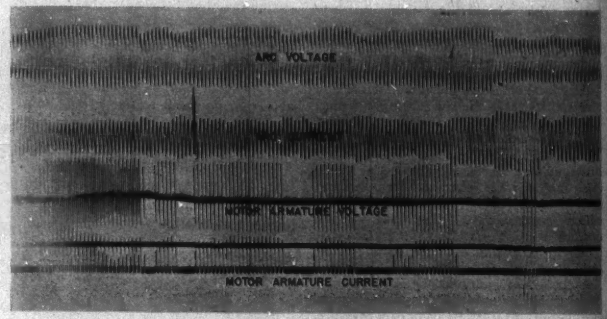

Figure 6. Oscillogram showing elecrical performance of regulator during refining period

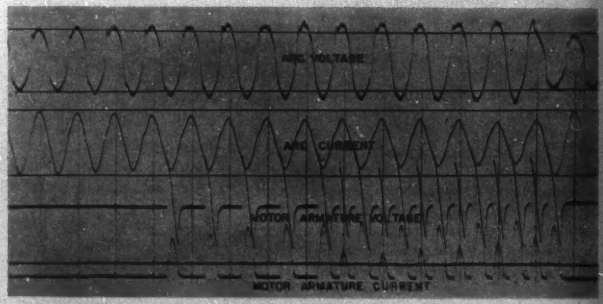

Figure 7. High-speed oscillogram showing electrical performance of regulator during refining period

film shows quite accurately the high speed of response. The picture shows the start of an unbalance and in less than two cycles voltage has been impressed across the motor armature. In 11 cycles the electrode has been returned to its desired position.

Operating experience has shown that the quick response of this regulator is particularly advantageous during melt-down periods when cave-ins frequently occur. The high-speed withdrawal of electrodes prevents breaker tripping due to sustained overload.

The regulator described in this paper was designed for a furnace which requires relatively small electrode motors by reason of using counterbalanced electrodes

Formulas for the Four-Terminal Network Parameters of Uniform Ladder Networks

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Synopsis: In the treatment of the over-all behavior of a smooth transmission line, or uniform ladder network, one frequently wishes to deal with the commonly termed *A-B-C-D* parameters rather than the propagation function, to which the former are related by hyperbolic functions, and the characteristic impedances. However, the latter are the functions which are simply related to the network components. The *A-B-C-D* parameters may be given as power-series expansions of the variable α, where $\alpha^2 = Z_T Y_T$ and Z_T and Y_T are the respective total series impedance and shunt admittance. For the smooth line these are infinite series; but they are terminating series for the ladder network, the number of terms and the coefficients of the terms being functions of the number (M) of elementary π or T sections of which the network is composed. Formulas for these coefficients are developed and they are given in several alternate forms. Also included are recurrence formulas and some relations among the coefficients of the different parameters. One form for the coefficients is particularly interesting because it shows that each coefficient for the ladder network is the corresponding smooth-line coefficient multiplied by a polynomial consisting of unity plus a polynomial in non-zero powers of $1/M^2$. This puts in evidence the manner in which the two coefficients approach each other as M increases; and also leads to easily computable upper and lower bounds of the ladder-network coefficients, which may provide useful estimates of their magnitudes.

The Parameters of Four-Terminal Networks

THE general theory of four-terminal networks is well known and may appear in any one of several forms, depending on the combinations of external currents and voltages which are to be related. In the present discussion we are interested in specifying the sending-end voltage and current, each in terms of linear combinations of both receiver voltage and current. In the general case of Figure 1, which may be a nonsymmetrical network, the required relations may be written

$$\left.\begin{aligned} E_s &= AE_r + B'I_r \\ I_s &= C'E_r + DI_r \end{aligned}\right\} \quad (1)$$

where the notation is that of the figure and A, B', C', and D are constants of proportionality. (The primes on B and C are used here merely to allow a uniform notation in the final results.) The theory of smooth lines and recurrent ladder networks is usually given in terms of the surge impedances (two in the case of a nonsymmetrical network) and the propagation function. However, this is an artificial point of view when one is interested in the over-all behavior of the circuit, considered as a four-terminal network, the parameters of equations 1 being more suitable. Occasion will arise in the subsequent discussion to compare the formulas for the ladder network with those for the smooth line. Therefore, we begin by putting the smooth-line parameters into forms suitable to our purpose. The following relations are well known:

$$\left.\begin{aligned} E_s &= (\cosh\alpha)E_r + \sqrt{Z_T/Y_T}(\sinh\alpha)I_r \\ I_s &= \sqrt{Y_T/Z_T}(\sinh\alpha)E_r + (\cosh\alpha)I_r \end{aligned}\right\} \quad (2)$$

where Z_T and Y_T are respectively the total series impedance and shunt admittance of the line, and $\alpha^2 = Z_T Y_T$. The parameters of relations 2 may be put into our final form by expanding cosh α and sinh α in McLaurin's series, giving

$$\left.\begin{aligned} A(\alpha) &= \cosh\alpha \\ &= 1 + \frac{\alpha^2}{2!} + \frac{\alpha^4}{4!} + \frac{\alpha^6}{6!} + \dots \quad \text{(a)} \\ B'(\alpha) &= Z_T \frac{\sinh\alpha}{\alpha} \\ &= Z_T\left(1 + \frac{\alpha^2}{3!} + \frac{\alpha^4}{5!} + \frac{\alpha^6}{7!} + \dots\right) \text{(b)} \\ C'(\alpha) &= Y_T \frac{\sinh\alpha}{\alpha} \\ &= (Y_T/Z_T)B'(\alpha) \quad \text{(c)} \\ D(\alpha) &= A(\alpha) \quad \text{(d)} \end{aligned}\right\} \quad (3)$$

It will be useful to introduce the notation

$$\left.\begin{aligned} B(\alpha) &= B'(\alpha)/Z_T \\ C(\alpha) &= C'(\alpha)/Y_T \end{aligned}\right\} = 1 + \frac{\alpha^2}{3!} + \frac{\alpha^4}{5!} + \frac{\alpha^6}{7!} + \dots \quad (4)$$

for future use.

Turning to a consideration of the ladder structure let us consider Figure 2 which shows, in the general case, the two possible forms of such a network. It is shown in Appendix I that for either of these circuits the parameters will be of the forms

$$\left.\begin{aligned} A(\alpha) &= a_0 + a_1\alpha^2 + a_2\alpha^4 + \dots a_{s_1}\alpha^{2s_1} \\ B(\alpha) &= b_0 + b_1\alpha^2 + b_2\alpha^4 + \dots b_{s_2}\alpha^{2s_2} \\ C(\alpha) &= c_0 + c_1\alpha^2 + c_2\alpha^4 + \dots c_{s_3}\alpha^{2s_3} \\ D(\alpha) &= d_0 + d_1\alpha^2 + d_2\alpha^4 + \dots d_{s_4}\alpha^{2s_4} \end{aligned}\right\} \quad (5)$$

The a, b, c, and d coefficients are functions of the k factors and it is further shown in Appendix I that, when the two circuits of Figure 2 are related as indicated in the figure, then

$$\left.\begin{aligned} A_a &= D_b \\ B_a &= C_b \\ C_a &= B_b \\ D_a &= A_b \end{aligned}\right\} \quad (6)$$

where the subscripts refer to the intended circuit of the figure. In view of this it is necessary to apply the future treatment to only the series-terminated network because the solution for the corresponding shunt-terminated circuit will be tacitly included. We will be dealing with a uniform network and therefore for our purpose $A = D$.

The Uniform Ladder Network

This discussion will apply to a ladder network consisting of M T sections with midseries termination. Such a circuit may be represented by Figure 2a in which $k_1 = k_N = 1/2M$ and all other k's are equal to $1/M$. In similarity with equation 2, when the network is specified by its characteristic impedance (Z_0) and propagation function (γ), we have the well-known relations

$$\left.\begin{aligned} E_s &= (\cosh M\gamma)E_r + Z_0(\sinh M\gamma)I_r \\ I_s &= (1/Z_0)(\sinh M\gamma)E_r + (\cosh M\gamma)I_r \end{aligned}\right\} \quad (7)$$

Thus, for this circuit

$$\left.\begin{aligned} A_T(\alpha) &= D_T(\alpha) = \cosh M\gamma \quad \text{(a)} \\ B_T(\alpha) &= (Z_0/Z_T)\sinh M\gamma \quad \text{(b)} \\ C_T(\alpha) &= (1/Z_0 Y_T)\sinh M\gamma \quad \text{(c)} \end{aligned}\right\} \quad (8)$$

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and hydraulic lowering and raising means. It is evident that the output energy of such a regulator depends on the rating and size of the electrode motor. The size of the furnace having balanced electrodes which this type of regulator can handle depends therefore on the energy requirements of the electrode motors. For other types of furnaces certain changes in design would be required such as braking means for the motors. In the application described this has not been found necessary, thus resulting in simplification of the regulating equipment.

The T subscript on A, B, and C is used to indicate that the network is made up of T sections. Furthermore, Z_0 and γ are given by[1]

$$\left.\begin{aligned} Z_0 &= \frac{\alpha\sqrt{4M^2+\alpha^2}}{2Y_T M} && \text{(a)} \\ e^{\gamma} &= \frac{\sqrt{4M^2+\alpha^2}+\alpha}{\sqrt{4M^2+\alpha^2}-\alpha} && \text{(b)} \end{aligned}\right\} \quad (9)$$

In view of relations 9, and with some reduction after substitution in equations 8, we obtain

$$\left.\begin{aligned} A_T(\alpha) &= \frac{(4M^2+\alpha^2)^M}{2(4M^2)^M}\times \\ &\quad \left[\left(1+\frac{\alpha}{\sqrt{4M^2+\alpha^2}}\right)^{2M}+\left(1-\frac{\alpha}{\sqrt{4M^2+\alpha^2}}\right)^{2M}\right] && \text{(a)} \\ B_T(\alpha) &= \frac{(4M^2+\alpha^2)^{M+1/2}}{\alpha(4M)(4M^2)^M}\times \\ &\quad \left[\left(1+\frac{\alpha}{\sqrt{4M^2+\alpha^2}}\right)^{2M}-\left(1-\frac{\alpha}{\sqrt{4M^2+\alpha^2}}\right)^{2M}\right] && \text{(b)} \\ C_T(\alpha) &= \frac{M(4M^2+\alpha^2)^{M-1/2}}{\alpha(4M^2)^M}\times \\ &\quad \left[\left(1+\frac{\alpha}{\sqrt{4M^2+\alpha^2}}\right)^{2M}-\left(1-\frac{\alpha}{\sqrt{4M^2+\alpha^2}}\right)^{2M}\right] && \text{(c)} \end{aligned}\right\} \quad (10)$$

The binomial theorem may be applied twice to finally arrive at a power-series representation of equations 10. The details of the conversion are given in Appendix II, and the results are

$$\left.\begin{aligned} A_T(\alpha) &= \sum_{\lambda=0}^{M} a_\lambda \alpha^{2\lambda} && \text{(a)} \\ B_T(\alpha) &= \sum_{\lambda=0}^{M} b_\lambda \alpha^{2\lambda} && \text{(b)} \\ C_T(\alpha) &= \sum_{\lambda=0}^{M-1} c_\lambda \alpha^{2\lambda} && \text{(c)} \end{aligned}\right\} \quad (11)$$

where

$$\left.\begin{aligned} a_\lambda &= \sum_{n=0}^{\lambda} \frac{(2M)!(M-n)!}{(2M)^{2\lambda}(2M-2n)!(2n)!\times (M-\lambda)!(\lambda-n)!} && \text{(a)} \\ b_\lambda &= \sum_{n=0}^{\lambda} \frac{(2M-1)!(M-n)!}{(2M)^{2\lambda}(2M-2n-1)!\times (2n+1)!(M-\lambda)!\times (\lambda-n)!} && \text{(b)} \\ c_\lambda &= \sum_{n=0}^{\lambda} \frac{(2M-1)!(M-n-1)!}{(2M)^{2\lambda}(2M-2n-1)!\times (2n+1)!(M-\lambda-1)!\times (\lambda-n)!} && \text{(c)} \end{aligned}\right\} \quad (12)$$

The preceding expressions are cumbersome but may be reduced to the following simple forms by the method indicated in Appendix III. The forms are:

$$\left.\begin{aligned} a_\lambda &= \frac{K_a(M,\lambda)}{(2\lambda)!} && \text{(a)} \\ \lambda &= \frac{K_b(M,\lambda)}{(2\lambda+1)!} && \text{(b)} \\ c_\lambda &= \frac{K_c(M,\lambda)}{(2\lambda+1)!} && \text{(c)} \end{aligned}\right\} \quad (13)$$

where

$$\left.\begin{aligned} K_a(M,\lambda) &= \frac{(M+\lambda-1)!}{M^{2\lambda-1}(M-\lambda)!} && \text{(a)} \\ K_b(M,\lambda) &= \frac{(2M^2+\lambda)(M+\lambda-1)!}{2M^{2\lambda+1}(M-\lambda)!} && \text{(b)} \\ K_c(M,\lambda) &= \frac{(M+\lambda)!}{M^{2\lambda+1}(M-\lambda-1)!} && \text{(c)} \end{aligned}\right\} \quad (14)$$

Equations 13 have been written with the factorials in evidence to bring out the similarity with the corresponding coefficients for a smooth line as given by equations 3a and 4. That is, the coefficients for a uniform ladder network are the corresponding coefficients for a smooth line multiplied by correction factors which are given explicitly by equations 14.

Relations Among the Coefficients

The similarities among formulas 14 leads one to look for useful relations among them, and the following recurrence formulas are immediately apparent.

$$\left.\begin{aligned} K_a(M,\lambda) &= \left[1-\left(\frac{\lambda-1}{M}\right)^2\right]\times K_a(M,\lambda-1) && \text{(a)} \\ K_b(M,\lambda) &= \left[1-\left(\frac{\lambda-1}{M}\right)^2\right]\times \frac{\left(1+\frac{\lambda}{2M^2}\right)}{\left(1+\frac{\lambda-1}{2M^2}\right)} K_b(M,\lambda-1) && \text{(b)} \\ K_c(M,\lambda) &= \left[1-\left(\frac{\lambda}{M}\right)^2\right]\times K_c(M,\lambda-1) && \text{(c)} \end{aligned}\right\} \quad (15)$$

In view of the complexity of equation 15b a possibly more useful form for $K_b(M,\lambda)$ is desirable, and may be obtained by expressing it in terms of $K_a(M,\lambda)$. For completeness a similar form is given for $K_c(M,\lambda)$. The results are self-evident from equations 14, and are

$$\left.\begin{aligned} K_b(M,\lambda) &= \left(1+\frac{\lambda}{2M^2}\right)K_a(M,\lambda) && \text{(a)} \\ K_c(M,\lambda) &= \left(1-\frac{\lambda^2}{M^2}\right)K_a(M,\lambda) && \text{(b)} \end{aligned}\right\} \quad (16)$$

Other relations can be found among the coefficients; but, because of their particular interest, only the following ones will be given. By writing equation 16b with λ replaced by $\lambda-1$ and substituting the resulting expression for $K_a(M,\lambda-1)$ in equation 15a one obtains the simple relation

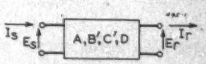

Figure 1

$$K_a(M,\lambda) = K_c(M,\lambda-1) \quad (17)$$

Two less obvious relations may be obtained by starting from fundamental equations of the network. From equations 8 and 9 one may obtain

$$B = (1+\alpha^2/4M^2)C \quad (18)$$

This is an identity and therefore when B and C are replaced by their series representations the corresponding coefficients of a given power of α, on the two sides of the equation, must be the same. Inspection shows that this leads to the result

$$b_\lambda = c_\lambda + \frac{1}{4M^2}c_{\lambda-1} \quad (19)$$

which is valid for all values of λ if c_{-1} is defined as zero. One obtains the second of these two relations by starting from the well-known formula[2]

$$A^2-1 = \alpha^2 BC = \left(\alpha^2+\frac{\alpha^4}{4M^2}\right)C^2 \quad (20)$$

Table I

λ	$K_a(M,\lambda)$ or $^*K_c(M,\lambda-1)$	$K_b(M,\lambda)$
0	1	1
1	1	$1+\frac{1}{2M^2}$
2	$1-\frac{1}{M^2}$	$1-\frac{1}{M^4}$
3	$1-\frac{5}{M^2}+\frac{4}{M^4}$	$1-\frac{7}{2M^2}+\frac{7}{2M^4}+\frac{6}{M^6}$
4	$1-\frac{14}{M^2}+\frac{49}{M^4}-\frac{36}{M^6}$	$1-\frac{12}{M^2}+\frac{21}{M^4}+\frac{62}{M^6}-\frac{72}{M^8}$
5	$1-\frac{30}{M^2}+\frac{273}{M^4}-\frac{820}{M^6}+\frac{576}{M^8}$	$1-\frac{55}{2M^2}+\frac{198}{M^4}-\frac{275}{2M^6}+\frac{1.474}{M^8}+\frac{1.440}{M^{10}}$

* This has no meaning for $\lambda=0$.

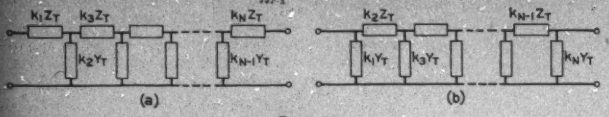

Figure 2

As in the previous case, one may substitute series for A and C and equate coefficients of like powers of α to give the formula

$$\sum_{q=0}^{\lambda} a_q a_{\lambda-q} = \sum_{q=0}^{\lambda-1} c_q c_{\lambda-1-q} + \frac{1}{4M^2} \sum_{q=0}^{\lambda-2} c_q c_{\lambda-2-q} \tag{21}$$

These last two relations (19 and 21) are superfluous so far as numerical computation is concerned but they are included for possible academic interest.

Additional Forms for the Coefficients

Neither of the forms so far given, in equations 12 or 13, for the coefficients gives a clear indication of how they vary with M, at a fixed value of λ. A better form, in this respect, may be obtained for $K_a(M, \lambda)$ and $K_c(M, \lambda)$ by the successive use of formulas 15a and 15c, and for $K_b(M, \lambda)$ by applying equation 16a to the new formula for $K_a(M, \lambda)$. The algebra of this transformation is self-evident, and the results are

$$\left.\begin{aligned} K_a(M,\lambda) &= \prod_{n=0}^{\lambda-1}\left(1-\frac{n^2}{M^2}\right) && \text{(a)}\\ K_b(M,\lambda) &= \left(1+\frac{\lambda}{2M^2}\right)\times \prod_{n=1}^{\lambda-1}\left(1-\frac{n^2}{M^2}\right) && \text{(b)}\\ K_c(M,\lambda) &= \prod_{n=0}^{\lambda}\left(1-\frac{n^2}{M^2}\right) && \text{(c)} \end{aligned}\right\} \tag{22}$$

From these it is seen that $K_a(M, \lambda)$ is a polynomial in even powers of $1/M$, the powers ranging from zero to $2\lambda-2$, inclusive; and that $K_b(M, \lambda)$ and $K_c(M, \lambda)$ are similar, but with even powers ranging from zero to 2λ, inclusive. Some of these polynomials have been computed and are given in Table I. It is interesting to note that equations 22 put in evidence the fact that a_λ and b_λ are zero if $\lambda > M$; and that c_λ is zero when $\lambda > M-1$. The form of equations 22 is particularly useful because it allows one to estimate the coefficients in terms of upper and lower bounds which may be obtained from the relation

$$\left[1-\left(\frac{\beta+1}{2M}\right)^2\right]^{\eta}\prod\left(1-\frac{\beta^2+1}{M^2}\right)^{[\beta/2]} < \prod_{n=0}^{\beta}\left(1-\frac{n^2}{M^2}\right) < \left[1-\left(\frac{\beta+1}{2M}\right)^2\right]^{\beta} < 1 \qquad \beta < M \tag{23}$$

in which $\eta = 0$ or 1, depending on whether β is even or odd, and $[\beta/2]$ is the greatest integer in $\beta/2$. The derivation is given in Appendix IV. Taking the right side of this inequality allows one to write

$$\left.\begin{aligned} a_\lambda &< \frac{1}{(2\lambda)!} && \text{(a)}\\ b_\lambda &< \left(1+\frac{1}{2M}\right)\frac{1}{(2\lambda+1)!} && \text{(b)}\\ c_\lambda &< \frac{1}{(2\lambda+1)!} && \text{(c)} \end{aligned}\right\} \tag{24}$$

which is interesting because the reciprocal factorials are the corresponding smooth-line coefficients.

The a, b, and c coefficients can be given in still another form, in terms of the hypergeometric function $F(r, s, t, x)$. When $x = 1$ this function reduces to[4]

$$F(r,s,t,1) = \frac{\Gamma(t)\Gamma(t-r-s)}{\Gamma(t-s)\Gamma(t-r)}, \qquad \text{if real part } (t-r-s) > 0, \tag{25}$$

which may be used to represent any one of the expressions in equations 14 by suitable choices for r, s, and t. The following results are given for combinations of r, s, and t which reduce the multiplying factors to simple forms; but other choices would be possible. The correctness of the choices will become evident upon making the indicated substitutions. The results are

$$\left.\begin{aligned} a_\lambda &= \frac{1}{M^{2\lambda-1}} F(1-M+\lambda, 1-2\lambda, 2, 1) && \text{(a)}\\ b_\lambda &= \frac{2M^2+\lambda}{4M^{2\lambda+1}} F(2-M+\lambda, 1-2\lambda, 3, 1) && \text{(b)}\\ c_\lambda &= \frac{1}{M^{2\lambda+1}} F(1-M+\lambda, -1-2\lambda, 1, 1) && \text{(c)} \end{aligned}\right\} \tag{26}$$

Conclusions

In view of the mathematical form of the results the formulas themselves are their most concise representation and only a few interpretive remarks are considered necessary. In the use of these results it is to be remembered that, as given, they apply to the midseries termination; but that the midshunt-terminated case is represented if B and C are interchanged. Of the several forms given probably equations 14 and 22 are the most important. If all the coefficients are to be found, equations 22, or the recurrence formulas which are practically the equivalent, will be found to be the more convenient. However, if only an isolated coefficient is wanted it may be computed more conveniently by employing equations 14 in conjunction with tables of logarithms of the factorials, or Stirling's approximation, which is

$$\log_{10} n! = (n+{}^1/_2)\log_{10} n - n\log_{10} e + ({}^1/_2)\log_{10} 2\pi \tag{27}$$

Equations 22 have the greater utility from the interpretive standpoint. It has already been pointed out that this form puts in evidence the number of nonzero coefficients in the series for each parameter. The form also leads to relation 23 which will yield a quick estimate of a coefficient and may therefore be useful when M and λ are large (but λ not too near M) and the required accuracy does not necessitate the more extended computation of the exact formula. This inequality also leads to the interesting results given in relations 24; namely, that the coefficients or the A and C parameters are always less than the corresponding smooth-line coefficients, and that, for the B parameter, the ladder-network coefficients are less than $(1+1/2M)$ times the corresponding smooth-line coefficient.

The treatment has been entirely in terms of the A-B-C parameters. However the four-terminal network may also be specified in terms of the driving-point and transfer impedances (or admittances). The results are readily extended to give the latter parameters as rational functions of α^2 because the two types of parameters are related by simple rational forms. This ability to easily write the parameters as rational functions would find practical application where one is required to find the zeros or poles of these functions (or rational combinations of them), with respect to the variable $p = d/dt$, because explicit means are available for finding the zeros of a polynomial. It is well known that such zeros and poles are of importance in circuit analysis. In relation to this discussion it should be noted that α^2 is a rational function of p when the network consists of lumped elements.

Appendix I

For the network of Figure 2a we may write the $(N+1)/2$ mesh equations

$$\left.\begin{aligned} E_1 Y_T &= I_1(k_1\alpha^2+1/k_2) - I_3/k_2\\ 0 &= -I_1/k_2 + I_3(1/k_2 + k_2\alpha^2+1/k_4) - I_5/k_4\\ &\cdots\cdots\cdots\cdots\cdots\\ 0 &= -I_{N-1}/k_{N-1} + I_T(1/k_{N-1} + k_N\alpha^2) + E_T Y_T \end{aligned}\right\} \tag{28}$$

where the numbered currents are the mesh currents which are numbered to correspond to the series impedances through which they flow. Figure 2b may be given a similar treatment, but on a nodal basis,[3] with the result which follows:

$$\left.\begin{aligned} I_s Z_T &= E_s(k_1\alpha^2+1/k_2)-E_s/k_2 \\ 0 &= -E_s/k_2+E_2(1/k_2+ \\ &\qquad k_2\alpha^2+1/k_4)-E_2/k_4 \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ 0 &= -E_{N-1}/k_{N-1}+E_r(1/k_{N-1}+ \\ &\qquad k_N\alpha^2)+I_r Z_T \end{aligned}\right\} \quad (29)$$

In these the voltage subscripts refer to the nodes at which the shunt elements having the same subscripts are terminated. It is seen that these two sets of equations are identical with respect to the k's and α, and are dually related with respect to voltage, current, impedance, and admittance. Equations 28 may be solved for E_s and I_s, in terms of E_r and I_r, and the solutions are

$$\left.\begin{aligned} E_s &= A(\alpha, k_1, k_2, \ldots)E_r+ \\ &\qquad Z_T B(\alpha, k_1, k_2, \ldots)I_r \\ I_s &= Y_T C(\alpha, k_1, k_2, \ldots)E_r+ \\ &\qquad D(\alpha, k_1, k_2, \ldots)I_r \end{aligned}\right\} \quad (30)$$

where A, B, C, and D are polynomials in α, the coefficients of which are functions of the k's. The above-mentioned relation between equations 28 and 29 shows that the solutions of equations 29 are

$$\left.\begin{aligned} I_s &= A(\alpha, k_1, k_2, \ldots)I_r+ \\ &\qquad Y_T B(\alpha, k_1, k_2, \ldots)E_r \\ E_s &= Z_T C(\alpha, k_1, k_2, \ldots)I_r+ \\ &\qquad D(\alpha, k_1, k_2, \ldots)E_r \end{aligned}\right\} \quad (31)$$

Relations 6 follow from a comparison of equations 30 and 31.

Appendix II

The method used to arrive at the formulas for A, B, and C for the uniform ladder network will be given by the use of A as an example. The same procedure was used for B and C. We start by expanding each of the binomials of equation 10a by the binomial theorem. The signs are such that odd powers of the argument cancel and we obtain

$$A=\frac{1}{(4M^2)^M}\sum_{r=0}^{M}\frac{(2M)!}{(2M-2r)!(2r)!}\times (\alpha^2)^r(4M^2+\alpha^2)^{M-r} \quad (32)$$

The binomial expansion may now be applied to the last term in the summation, giving

$$A=\sum_{r=0}^{M}\frac{(2M)!}{(4M^2)^r(2M-2r)!(2r)!}(\alpha^2)^r\times \sum_{s=0}^{M-r}\frac{(M-r)!}{(M-r-s)!(s)!}\left(\frac{\alpha^2}{4M^2}\right)^s \quad (33)$$

which may be written as

$$A=\sum_{r=0}^{M}\frac{(2M)!}{(2M-2r)!(2r)!}\times \sum_{s=0}^{M-r}\frac{(M-r)!}{(M-r-s)!(s)!}\left(\frac{\alpha^2}{4M^2}\right)^{r+s} \quad (34)$$

This is conveniently transformed by changing the summation indices to r and u, where $u=r+s$, resulting in

$$A=\sum_{r=0}^{M}\frac{(2M)!(M-r)!}{(2M-2r)!(2r)!}\times \sum_{u=r}^{M}\frac{1}{(M-u)!(u-r)!}\left(\frac{\alpha}{2M}\right)^{2u} \quad (35)$$

The above may be rearranged by factoring out the various powers of α. For example, let λ be a particular value of u, it being obvious that λ may be between 0 and M, inclusive. For this value, one coefficient of $\alpha^{2\lambda}$ will be obtained for each value of r in the first summation for which $\lambda \geqq r$, because the lower limit on the second summation is r. Thus, r may be replaced by another index (n) which runs from 0 to λ, inclusive, and the result is as given by the combination of equations 11a and 12a.

Appendix III

An outline of the complete proof for the reduction to forms 14 will be given for a_λ. The usual notation for a binomial coefficient will be used, namely

$$\binom{p}{q}=\frac{p!}{q!(p-q)!}$$

In this notation we are to prove

$$\sum_{n=0}^{\lambda}\binom{2M}{2n}\binom{M-n}{\lambda-n}=\frac{2^{2\lambda}M(M+\lambda-1)!}{(2\lambda)!(M-\lambda)!} \quad (36)$$

The method is to write the function

$$\phi(x)=(1-x^2)^{-M+\lambda-1}(1+x)^{2M}=\sum_{q=0}^{\infty}G_q x^q \quad (37)$$

and obtain two expressions for $G_{2\lambda}$, one which will be the left side of equation 36 and the other which will be the right side. The function is analytic and the series converges when $|x|<1$. With some manipulation for the first of the following forms, and directly for the second, one obtains

$$\left.\begin{aligned} (1-x^2)^{-M+\lambda-1} &= \sum_{r=0}^{\infty}\binom{M-\lambda+r}{r}x^{2r} \quad \text{(a)} \\ (1+x)^{2M} &= \sum_{s=0}^{2M}\binom{2M}{s}x^s \quad \text{(b)} \end{aligned}\right\} \quad (38)$$

$G_{2\lambda}$ is obtained from equations 38 by summing the product of the general terms of these two series over all values of r and s such that $r \geqq 0$, $0 \leqq s \leqq 2M$, and $2r+s=2\lambda$. Thus, s must be even, say $2n$, and therefore $r=\lambda-n$. With the substitution of these in the general terms of equations 38, and taking their products, one arrives at the left side of equation 36.

The second part of the proof is obtained from the Cauchy integral formula for $\phi^{(2\lambda)}(0)/(2\lambda)!$ (the McLaurin-series coefficient of $x^{2\lambda}$). This formula is

$$G_{2\lambda}=\frac{1}{2\pi j}\int_C\frac{\phi(x)}{x^{2\lambda+1}}dx \quad (39)$$

where C is a circle of radius less than unity, with its center at the origin, and over which the integration is to be in a counterclockwise direction. The integral is easily evaluated by employing the change of variable $x=1/u$ which results in

$$G_{2\lambda}=\frac{1}{2\pi j}\int_{C'}u(u+1)^{M+\lambda-1}(u-1)^{-M+\lambda-1}du \quad (40)$$

taken counterclockwise about the origin on a circle of radius greater than unity. The integrand has a pole at $u=1$, which is inside the path of integration, and is analytic everywhere else inside the path of integration. Hence, $G_{2\lambda}$ is the residue of the integrand at $u=1$. The Laurent series for $\psi(u)$, the integrand, may be shown to be

$$\psi(u)=2^{M+\lambda-1}\sum_{r=0}^{M+\lambda-1}\frac{1}{2^r}\binom{M+\lambda-1}{r}\times (u-1)^{-M+\lambda-1+r}+2^{M+\lambda-1}\times \sum_{r=0}^{M+\lambda-1}\frac{1}{2^r}\binom{M+\lambda-1}{r}(u-1)^{-M+\lambda+r} \quad (41)$$

The residue is the coefficient of $(u-1)^{-1}$ and is obtained by putting $r=M-\lambda$ in the first sum, and $r=M-\lambda-1$ in the second. The resulting form is readily reducible to the right side of equation 36.

Similar proofs may be given for equations 14b and 14c. In both cases one finds two formulas for the coefficient of $x^{2\lambda+1}$ in the expansion of $\phi(x)$; but in the case of equation 14c the function $(1-x^2)^{-M+\lambda}$ is substituted for $(1-x^2)^{-M+\lambda-1}$ in $\phi(x)$.

Appendix IV

To arrive at relation 23 observe that the continued product may be written

$$\prod_{n=0}^{\beta}\left(1-\frac{n^2}{M^2}\right)=\left[1-\left(\frac{\beta+1}{2M}\right)^2\right]^{\eta}\times \prod_{n=0}^{\left[\frac{\beta}{2}-1\right]}\left[1-\left(\frac{\frac{\beta+1}{2}-\Delta}{M}\right)^2\right]\times \left[1-\left(\frac{\frac{\beta+1}{2}+\Delta}{M}\right)^2\right] \quad (42)$$

where

if β is even, $\eta=0$ and $\Delta=n+1/2$
if β is odd, $\eta=1$ and $\Delta=n+1$

and the brackets on $\beta/2-1$ indicate the greatest integer in $\beta/2-1$. The continued

Improved Selective Tripping of Low-Voltage Air Circuit Breakers

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SINCE the first devices for interrupting short-circuit currents in electric systems were invented, the problem of having them operate to clear faults without removing energy from normal circuits has existed. Many devices, both separate and as parts of the interrupters, have been developed and good results obtained. Systems having potentials below 600 volts alternating current normally use air interrupting devices designed particularly for this service.

The normal utilization of a-c power in industrial plants or generating station auxiliary circuits where the average individual load is less than about 75 horsepower is at 600 volts or less. Occasional larger loads and groups of smaller loads, switched as units, require a considerable range in both current-carrying capacity and interrupting ability of circuit breakers. The standard devices available have current ratings up to 6,000 a-c amperes and 100,000 amperes interrupting rating. Larger units have also been built to a limited extent.

When a large number of small loads are supplied, the total power required determines the size of the generating or transforming apparatus and thus indirectly the values of fault currents. Even though individual loads may be small, high interrupting requirements may dictate the use of relatively large circuit breakers. They may become so large that their cost is out of proportion to the motors or other devices to which they supply power. The economics of low-voltage system design, therefore, require circuit arrangements which will permit the use of the smallest possible switching devices. At the same time, selective isolation of faults is highly desirable. However, this is frequently partially sacrificed in special circuits arranged to permit the use of circuit breakers in duty above their interrupting ratings (cascading). New developments in built-in tripping devices will provide full selectivity without the use of separate relays in normal breaker applications and increase the ranges of reliable selective tripping in special circuit arrangements in which breakers are applied whose interrupting capacities are below the value of maximum fault currents.

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Selective Tripping With Breakers Having Full Interrupting Ability

Circuit breakers supplying power to loads should operate to clear only faulted circuits and not interrupt energy to other parts of the system. This requirement can sometimes be modified, but in circuits for essential central-station auxiliaries and certain industrial processes, maximum continuity of service is essential. This means, referring to Figure 1, that breakers *A*, *B*, and *C* must have interrupting capacity fully equal to the fault currents which may occur, that they must have time discrimination on tripping, and that they must have short-time ratings adequate for the time and current to which they will be subjected. These distinctions, as compared with the special "cascade" arrangement discussed later, where only limited selectivity is obtainable, should be kept in mind throughout the following discussion.

The problems arising from selective tripping are all recognized in high-voltage breaker applications and standard devices meet them. These are usually protective relays which open the breakers by energizing their shunt trip coils. The situation on low-voltage air breakers is somewhat different. The designs of all manufacturers have almost uniformly included instantaneous trip attachments operating at 15 times normal current on ratings below 2,000 amperes and 12 times normal above this value. No short-time current ratings were assigned. This has meant that the amount of conducting material in the contacts is relatively less than has been considered necessary in high-voltage designs. Moves are now under way to assign short-time ratings to all low-voltage breakers. However, the maximum values possible for existing breakers, for reasons just explained, probably will be somewhat lower compared to the interrupting current rating, than has been the case with high-voltage power breakers. This must be taken into consideration in applying breakers where intentional time delay in tripping is introduced to obtain selectivity and affects cost as compared to the cascade arrangement described in detail later.

When breakers *B* and *C* are in separate structures and connected by cables, the problem of protecting these cables enters the picture. A relatively long tripping time is desirable, operating at the cable current capacity, a shorter tripping time within the short-time current rating of the breaker is needed for selectivity and instantaneous tripping above this current. Present commercially available self-contained tripping devices offer only the time characteristics of oil dashpots or thermal devices and these, at best, are questionable. Protective relays offer the best available means for obtaining the tripping time values necessary for these various current values.

Many engineers are satisfied to have short-circuit protection only on power supply cables on the basis that they are protected from overloads by the feeder breakers. This is sound practice on a properly designed distribution system,

product on the right side of equation 42 may be written

$$\prod_{n=0}^{\left[\frac{\beta}{2}-1\right]}\left[1-\frac{\beta^2+2\beta+1+4\Delta^2}{2M^2}+\frac{(\beta^2+2\beta+1-4\Delta^2)^2}{16M^4}\right] \quad (43)$$

A lower bound of this quantity may be obtained by neglecting the third term and assigning to Δ its largest value, namely $(\beta-1)/2$ in each case. Similarly, an upper bound will result if $4\Delta^2$ is neglected in all terms. These substitutions, by eliminating the variable n, permit the substitution of an exponent for the product, and readily yield the results given in relation 23.

References

1. COMMUNICATION NETWORKS (book), E. A. Guillemin. John Wiley and Sons. Volume II, page 178.

2. Reference 1, page 139.

3. ELECTRIC CIRCUITS (book), Massachusetts Institute of Technology staff. John Wiley and Sons. Page 463.

4. MODERN ANALYSIS (book), Whittaker and Watson. Cambridge University Press. Fourth edition, page 281.

but there are arrangements where the best planning cannot eliminate the hazard of overloading. In these cases, discriminatory tripping must be provided or continuity of service partially sacrificed.

The application of relays for obtaining selective tripping with suitable breakers on the basis of time discrimination is well understood and only self-contained tripping devices will be considered here.

Cascaded Breakers

If we refer again to Figure 1 which illustrates typical circuits, it is evident that if breaker *B* and one of the *C* breakers both open at substantially the same time to clear a fault, the interrupting duty on *C* will be materially reduced. If tripping devices are supplied for *B* so that this will always take place, then a smaller breaker can under certain conditions be used in position *C* than would have been possible in the circuits described previously. A similar relation exists between breakers *A* and *B*. This often results in a material saving in the cost of circuit breakers. The advantages, limitations and conditions determining the selection of interrupting devices in cascade circuits of this kind will be considered.

Manufacturers have recognized the advantages of this arrangement and have approved special cascaded circuits as covered by the following definition in the National Electrical Manufacturers Association Standards.

"Cascading is the application of air circuit breakers in which only the breakers nearest the source of power shall have interrupting ratings equal to, or in excess of, the obtainable fault current while breakers in succeeding steps further from the source may have successively lower interrupting ratings."

The relative allowable reduction in interrupting rating of the breakers in successive steps is limited as follows. Group breakers *B* may have 50 per cent of the interrupting requirements of main breaker *A* and branch breakers *C* in turn may have one-third the rating of the main breaker which must be able to open on a standard duty cycle the maximum fault current which the power supply can deliver. Cascading is limited to three steps of interrupting rating. In many applications, this represents a great saving in breaker cost as compared to an installation in which all devices have full interrupting ability. However, it must be realized that this saving is not obtained without some risk and sacrifice in over-all performance.

The main and group breakers must be free to trip instantaneously to afford maximum protection to the smaller branch breakers which are allowed to be of reduced interrupting ratings. This requirement is the all-important and definite difference between cascaded and similar circuits previously described in which all breakers have the same full interrupting ability and selectivity of tripping depends on time discrimination.

The instantaneous tripping devices of the main and group breakers must be

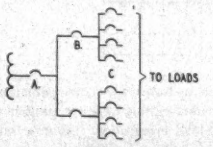

Figure 1. A common arrangement of low-voltage breakers

set at about 80 per cent of the interrupting rating of those in the next lower step in the cascade. This margin is necessary to allow for some manufacturing variances and to insure that the speed of opening will not be too slow at currents just over the interrupting ability of the breaker in the next lower step. These trip calibrations mean that faults on load circuits may open the group or even the main breaker depending on whether the current reaches the trip settings of these devices. This limitation is fundamental in the cascade arrangement and must be accepted as one of the offsetting factors against the savings in equipment.

At present, low-voltage air breakers have no published short-time current ratings. These are being determined by

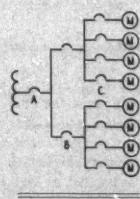

Figure 2. A typical cascaded power supply to motors listing the breaker characteristics for co-ordinated mechanically timed tripping

	Breaker *A*	Breaker *B*	Breaker *C*
Current rating, amperes	1,600	600	50
Interrupting rating, amperes	50,000	25,000	15,000
Half-second short-time rating, amperes	25,000	18,000	10,000
Instantaneous trip setting, amperes	20,000	14,400	500
Time-delayed trip settings, seconds	0.4	0.2	*

* Thermal time delay set to allow motor starting and provide motor overload protection.

test for existing designs and will soon be announced. When this takes place, the tripping devices on main and group breakers may be set to allow delayed tripping up to their short-time rating with instantaneous opening at currents above this figure. It is apparent that better continuity of service and selective isolation of faults will be obtained under these conditions. However, there will still be many conditions in cascaded circuits having breakers with successively reduced interrupting and short-time ratings where opening must be instantaneous.

At this point, it should be noted that the short-time ratings which can be assigned to low-voltage breakers designed for instantaneous opening on 12 or 15 times their continuous rating will have to be materially lower than their interrupting rating. This does not parallel the situation on higher-voltage circuit breakers where short-time ratings equal or occasionally exceed their interrupting ratings. It is also very doubtful whether the cost of future low-voltage designs should be increased to provide higher short-time ratings. Most applications can be satisfied with present constructions and an increased number of standard ratings is not economically desirable. The requirements of a few applications should not burden all the others by dictating high short-time ratings in all standard designs.

A reference to Figure 1 will make it evident that:

1. Breaker *B* must open instantaneously when its short-time rating is exceeded.
2. In the cascade arrangement, with successively smaller steps of interrupting capacity and short-time ratings, close-in faults on feeders may exceed the short-time ratings of the group breaker.
3. Consequently selective tripping is not always possible.

A further condition applying to cascaded breakers is the restricted duty cycle which is imposed. A breaker operated within its rating is allowed maximum-current "O" and "CO" operations separated by a two-minute interval and should be able to carry rated load after such openings. Breakers operating above their rating in a cascade circuit are restricted by requiring inspection and possible maintenance after each opening on fault current. This means that it is not safe to reclose cascaded breakers, even once, without inspection if two in series have cleared a short circuit. The smaller breaker might be damaged so that, even though its contacts completed the circuit, they would not safely carry

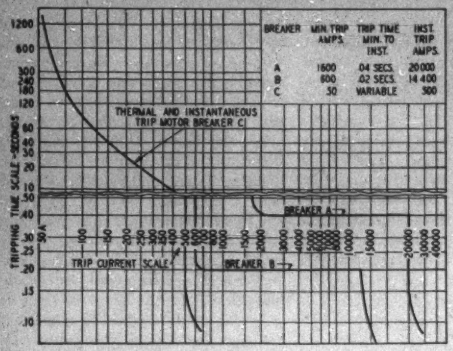

Figure 3. Time–current tripping coordination of cascaded breakers with integral mechanically delayed trips

The horizontal lines represent time bands of appreciable width and must be separated approximately as shown

load current. Inspection is necessary after each fault opening when breakers are applied with inadequate interrupting ability as in cascaded circuits.

To sum up the case for cascaded breaker circuits; on the affirmative side, breaker expense is often materially reduced; on the negative side, continuity of power is partially sacrificed, increased breaker maintenance may be expected, and a more limited duty cycle is specified for most of the breakers. Cascade arrangements applied with a full understanding of these conditions should prove satisfactory.

Cascaded Breakers With Selective Tripping

New definite-time tripping devices are being developed which will give breakers so equipped equal or better selectivity than is obtainable with relays, and will also improve the operation of cascade arrangements. Tests with as many as three breakers in series have shown accurate selective tripping with a maximum time setting of less than one-half second on the largest breakers. The diagram, Figure 2, has been prepared to illustrate such conditions. This arrangement of breakers will provide instantaneous tripping in the ranges required to permit a cascaded circuit with the allowed reduction in interrupting rating in each breaker step farther from the supply. The consequent economics are realized and the new tripping devices will function to give all the selectivity which the chosen breakers will permit.

Let us now review the operation of this cascaded circuit under a number of fault and load conditions. Assume motor *M* has a full-load current of 50 amperes. Breaker *C* will provide the usual thermal protection. It will open instantaneously on a motor fault exceeding ten times normal or 500 amperes. If the fault is over 15,000 amperes, that is, above the interrupting ability of *C*, breaker *B* will open instantaneously to back up *C* and so on up through the current range and breaker series. If the fault is below 15,000 amperes but for some reason breaker *C* fails to clear, breaker *B* will still open in 0.2 second. If it, in turn, should not interrupt, breaker *A* will open in 0.4 second. Faults which occur anywhere in the circuit will:

1. Open the nearest breaker.
2. Open the next larger breaker instantaneously if its assistance is needed for interruption.
3. Open the latter breaker in a slightly longer time if the current is within the interrupting ability of the first breaker, but it has failed to clear.
4. Open succeeding breakers in a similar manner if needed.

Reference to Figure 3 will show the current and time characteristics which give these results.

Considering the time intervals during which breakers will be subjected to high fault current in this arrangement, breaker *C* would be a thermally tripped breaker with a self-protecting instantaneous trip set at 500 amperes, breaker *B* would be set to open in 0.2 second on currents up to 14,400 amperes, 80 per cent of its short-time rating, and breaker *A* would be set to trip in 0.4 second, up to 20,000 amperes, 80 per cent of its half-second rating. This allows each breaker, provided its short-time rating is not exceeded, to hold in a sufficient time for the breaker next lower in the cascade to clear. This ensures that all breakers adequate to carry fault current arising from a short circuit remain closed and all others trip.

It is evident that the above degree of selective tripping gives discriminatory opening up to the capacity of the breakers in the cascaded circuit. No better selectivity is possible with breakers applied in accordance with standard cascading practice. However, there may be fault current values where group breakers occasionally open and de-energize unfaulted circuits. The savings due to the use of smaller breakers will usually justify this. However, a similar circuit made up entirely of breakers with definite-time tripping attachments, full interrupting ability, and adequate short-time ratings will give complete selectivity without the use of relays and shunt trip coils.

It has been shown, first, that full selectivity could be obtained with breakers having full interrupting ability and adequate short-time ratings in all steps and tripped by relays giving definite time discrimination in faults. Second, the possibilities and economies of cascaded breakers and the limitations of this system were considered. Third, it was explained that new tripping devices are being developed for standard breakers combining instantaneous and time-delay tripping features so that the economics of cascaded breakers can be realized and short-time ratings and interrupting ability used to the best advantage to give maximum permissible selectivity. It was also pointed out that adequate breakers with definite-time tripping devices in all positions can give complete selectivity, the equivalent of which has previously been possible only with relays, shunt trips, and storage batteries. Thus we advance another step in the economic use of materials coupled with a better accomplishment of purpose in improved continuity of service.

The Degree of Short-Circuit Protection Afforded Small Low-Voltage A-C and D-C Starters by Means of Fuses and Circuit Breakers

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AIEE technical paper 42-79, entitled "Thermal Co-ordination of Motors, Control, and Their Branch Circuits on Power Supplies of 600 Volts and Less,"[1] was presented in April 1942. The purpose of the article as stated was "to show what the characteristics of the protective devices should be in order that the power will be disconnected from the main feeders under all conditions of excess current before excess temperatures are attained." After the overload protecting requirements were discussed, it was pointed out that "to protect the conductors in the branch circuit adequately, the control devices, and the motor winding, we must use a device that is both fast in opening the circuit and also has the necessary interrupting ability." In discussing the speed and the interrupting abilities of circuit breakers and fuses which were used to protect the motors and the controls against short circuits, the following statement was made:

"The second half of the question dealing with the amount of available energy which these fuses can interrupt was determined by providing a 250-volt d-c source which was capable of delivering 96,000 amperes and also a three-phase source which was capable of delivering an rms symmetrical current of 84,000 amperes at 440 volts and 114,000 amperes at 600 volts. In the d-c circuit were placed two standard nonrenewable General Electric 250-volt fuses in series to simulate the usual two fuses that are in a circuit. Two 600-volt fuses were also tested in this circuit wherein the available currents were varied from 10,000 to 96,000 amperes in several steps, and the results were perfect. The buildup of the current in this circuit was much slower than in an a-c circuit so that the current-limiting effects were much more pronounced as shown in Figure 7.

"In the three-phase 440-volt a-c circuit one 250-volt fuse of the preceding type was connected in each supply line, and the available currents ranged from 18,000 to 84,000 symmetrical rms amperes. The resulting currents are shown in Figure 6, and the performance was perfect. When the supply power was 600 volts, then one 600-volt fuse was connected in each supply line, and the available current ranged from 24,000 to 114,000 amperes. The results are also shown on Figure 6 which was perfect in operation. It can be said therefore that *with this arrangement of connections* (note that Figure 6 gives the impedance of each combination of the a-c circuits), these fuses are capable of interrupting a circuit, either a-c or d-c, which has an available short-circuit current of 100,000 amperes."

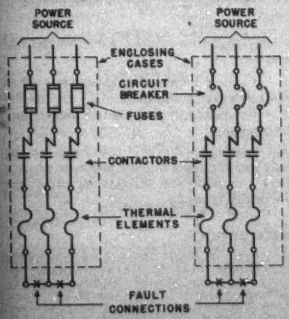

Figure 1. Arrangement of connections for fuses or circuit breakers when used for protecting a-c starters

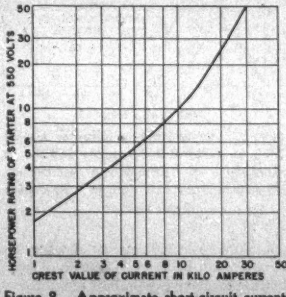

Figure 2. Approximate short-circuit currents (crest value) which will flow through a three-phase across-the-line starter when connected to a 550-volt three-phase supply that has an available current of 50,000 rms symmetrical amperes—short circuit on load side of starter

The preceding statement regarding the interrupting abilities of fuses has been interpreted by some differently from the original intent, and it is the purpose of this supplementary paper to point out the interpretation which should be made. Some further data will be submitted to show the relative protecting characteristics of these fuses and of some small-size air circuit breakers which are commonly used for protecting small-size starters.

As was stated in the purpose of the article, the investigation was to ascertain the degree to which the fuses and the circuit breakers would protect the starters from damage due to short circuits passing through the starters. Therefore, every test had a starter in series with either a set of appropriate-size fuses or a corresponding-size circuit breaker as illustrated in Figure 1 of this present paper. Therefore the amount of current which would flow was affected appreciably by the size of starter that was in the circuit. The original statement was not intended to imply that the fuses would give the same performance when the starters were omitted from the circuit. As previously noted, it stated that *with this arrangement of connections* the fuses were capable of interrupting a circuit having an available current of 100,000 amperes.

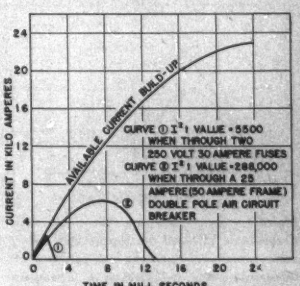
CURRENT IN KILO AMPERES
AVAILABLE CURRENT BUILD-UP
CURVE ① I²t VALUE = 5500 WHEN THROUGH TWO 250 VOLT 30 AMPERE FUSES
CURVE ② I²t VALUE = 288,000 WHEN THROUGH A 25 AMPERE (50 AMPERE FRAME) DOUBLE POLE AIR CIRCUIT BREAKER
TIME IN MILI SECONDS

Figure 3. Current build-up following a short circuit on a 250-volt d-c supply and the I^2t values which were permitted to pass through 30-ampere fuses and through a 25-ampere circuit breaker

To emphasize further the importance of this difference, Figure 2 shows the approximate current which would flow if various sizes of three-phase starters, rated according to horsepower at 550-volt three-phase power supply, which had an available short-circuit current of 50,000 rms symmetrical amperes, were connected to the supply when a three-phase short circuit was placed on the load side of the starters. This shows that the value of the short-circuit current is determined more by the size of the starter, for the sizes under con-

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B. W. JONES is consulting engineer in the industrial-control engineering department of General Electric Company, Schenectady, N. Y.

sideration, than by the size of the power supply. Therefore, the small-size fuses have to interrupt the smaller currents and the larger fuses the larger currents which is in accordance with their abilities. Therefore, our tests showed that when the several features that were enumerated in the original paper obtained, then the fuses were able to give the necessary protection as originally claimed.

These data also emphasize the importance of combining the short-circuit protecting means and the starter into one enclosure as illustrated in Figure 1 so as to minimize the probability of a short circuit occurring between the protecting means and the starter. Then, if the short circuit should require the assistance of the protecting means, the starter will be in the path of the short circuit, and the resultant current will be within the range of what the fuse can handle.

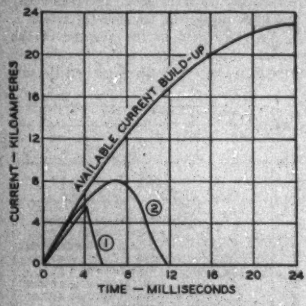

Figure 4. Current build-up following a short circuit on a 250-volt d-c supply and the I^2t values which were permitted to pass through 60-ampere fuses and through a 50-ampere circuit breaker

Curve 1 I^2t value = 62,000 when through two 250-volt 60-ampere fuses

Curve 2 I^2t value = 352,000 when through a 50-ampere double-pole circuit breaker

Also, in support of the superior protection claimed for the fuses in contrast to the protection which circuit breakers give to those small-size starters (size 3 and less), Figures 3, 4, and 5 are offered. The comparison shown is the I^2t values (the current squared times the duration in seconds) which two 250-volt fuses of the 30-, 60-, and 100-ampere sizes and double-pole circuit breakers (standard 50- and 100-ampere frame sizes of breakers) permitted to flow into a short circuit from a 250-volt d-c supply which had an available short-circuit current of 23,000 amperes. The I^2t values which these two devices permit to get through into a short circuit is a direct measure of the amount of heat that will be put into some thermally weak member that should be protected. The reason why a d-c supply was chosen on which to base this comparison was that in many cases it is essential that this short circuit be removed in less than one-half cycle, and if direct current is used then the initial rate of current build-up and the voltage at interruption always will be the same, and whatever difference there is in the I^2t value will be due to the difference in the interrupting characteristics of the two devices. In these three figures the available current from the power source is plotted and, curve 1 the build-up and cutoff as determined by the fuse, and curve 2 the buildup and cutoff as determined by the circuit breaker. It will be noted that two 30-ampere 250-volt fuses are compared to a double-pole 25-ampere (50-ampere frame) circuit breaker; two 60-ampere fuses are compared to a double-pole 50-ampere circuit breaker; and two 100-ampere fuses are compared to a double-pole 100-ampere (100-ampere frame) circuit breaker. These data show that the respective I^2t values which these devices permitted to pass were 5,500 versus 288,000; 62,000 versus 352,000; 170,000 versus 582,000. This very definitely p oves that the fuse does a very much superior job in protecting the smaller device against excess energy.

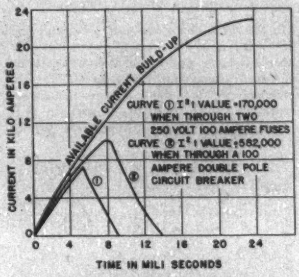

Figure 5. Current build-up following a short circuit on a 250-volt d-c supply and the I^2t values which were permitted to pass through 100-ampere fuses and through 100-ampere circuit breakers

Because of the aforementioned situation, it may be constructive to show the range of thermal capacity of the heaters of the overload relays which are very commonly the thermal limiting factor on most starters. The minimum curve in Figure 6 shows the I^2t values which the overload relay heaters may be able to withstand. As already shown, the 60-ampere fuse would be used in conjunction with an overload relay rated about 17 or 18 amperes, and Figure 6 shows that the minimum value may be about 70,000, and the test data showed that the fuse permitted 62,000 to get through but the circuit breaker permitted 352,000 to pass. The maximum curve shows that there are some forms of relays which have a permissible I^2t value of 700,000. But, since the trend is toward the faster tripping relay so as to protect the fast-heating motors, it is advisable that the fast short-circuit protective means be used so as better to protect either the fast- or the slow-heating type of overload relays.

Conclusions

When we consider that:

1. The fuse is capable of interrupting a short circuit on a large power supply of either alternating or direct current if the starter is in the path of the short circuit.

2. Under some conditions, the 30-ampere fuse will allow only *two per cent* and the 60- and 100-ampere fuses will allow only 25 to 30 per cent of what similar-size circuit breakers will permit to reach a short circuit under similar circumstances.

3. The general trend of motors is to require faster overload relays, and these faster relays generally will have less thermal capacity (more expensive and larger relays can be fast and still have large thermal capacity), but the user cannot be sure when purchasing control from the general market.

4. If a slow interrupting means is used to protect against short circuits, the starter may be damaged, and the personnel may be injured.

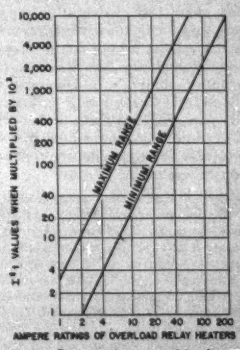

Figure 6. Range of permissible I^2t values which may be found in overload relays

The logical conclusion is that fuses are the only satisfactory available means to protect fully the small-size starters of either the a-c or d-c types.

Reference

1. Thermal Co-ordination of Motors, Control, and Their Branch Circuits on Power Supplies of 600 Volts and Less, B. W. Jones. AIEE Transactions, volume 61, 1942, July section, page 483–7.

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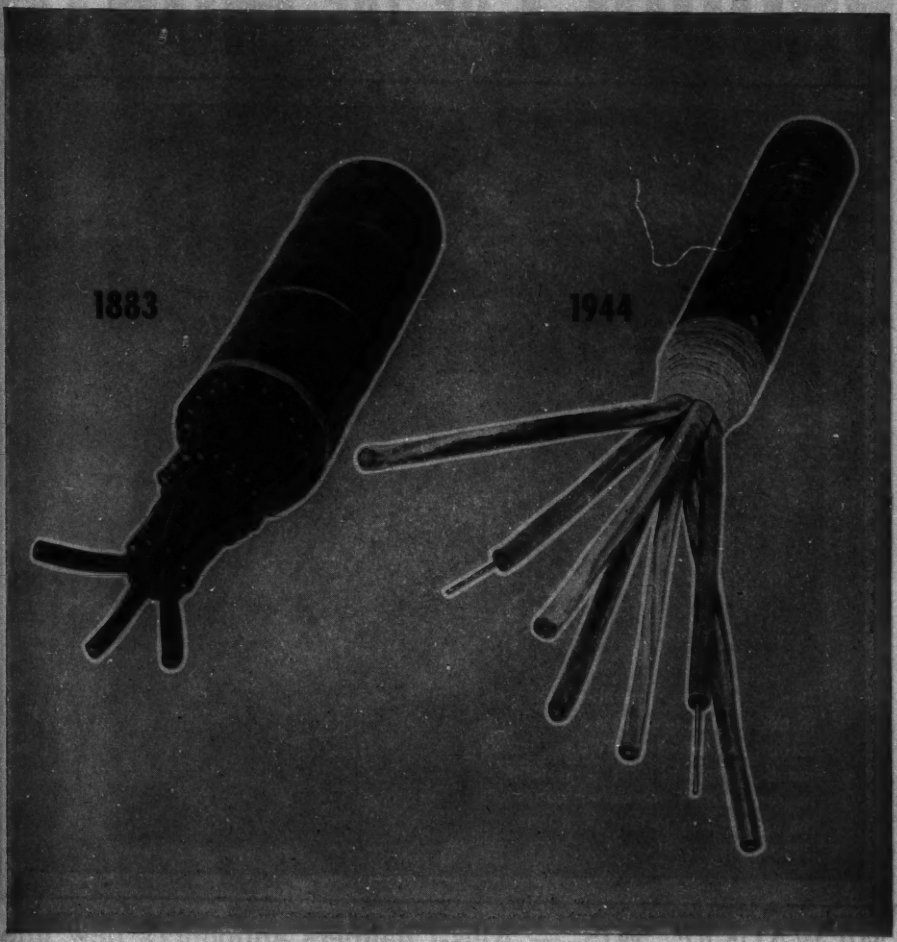

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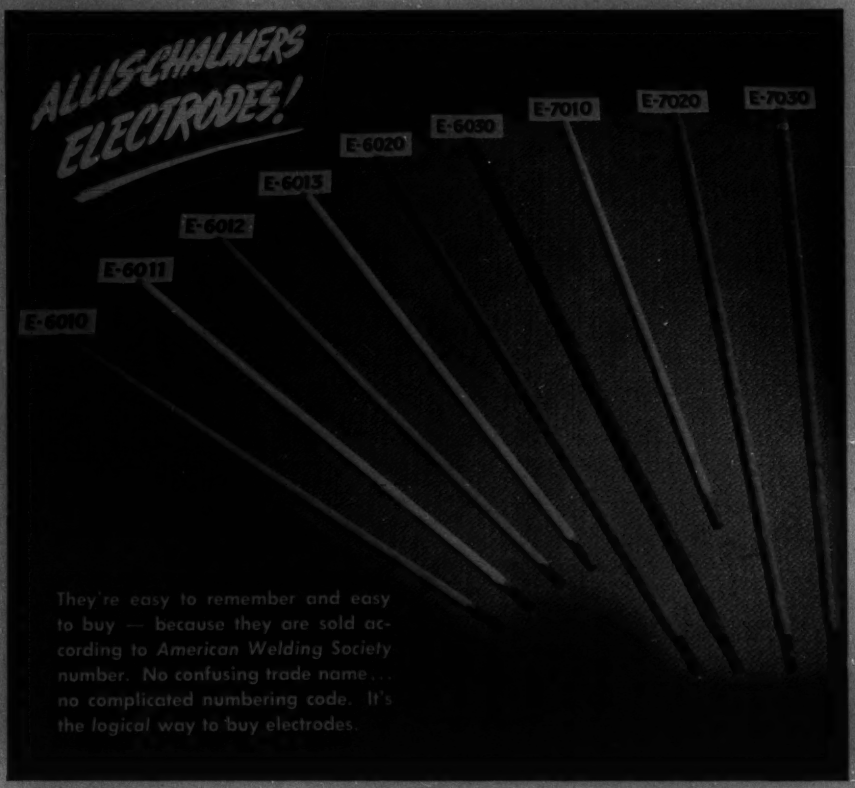
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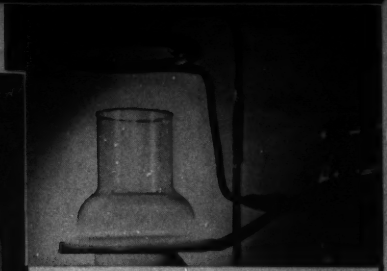

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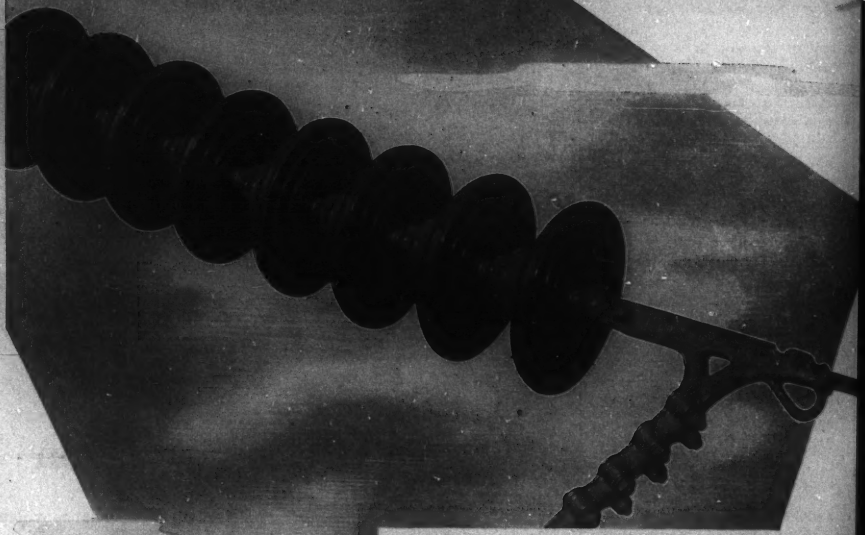

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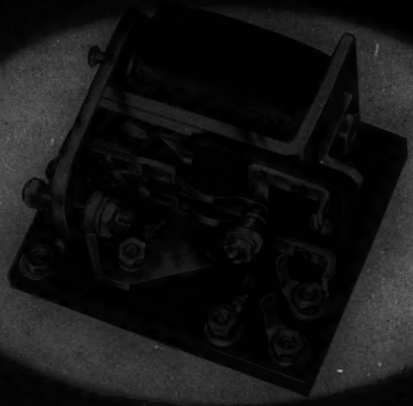

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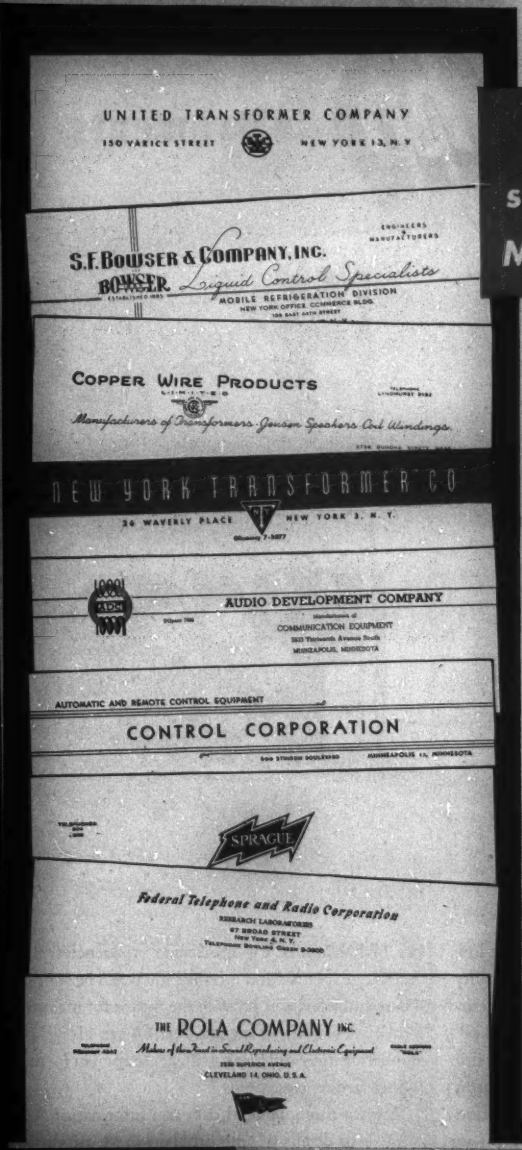

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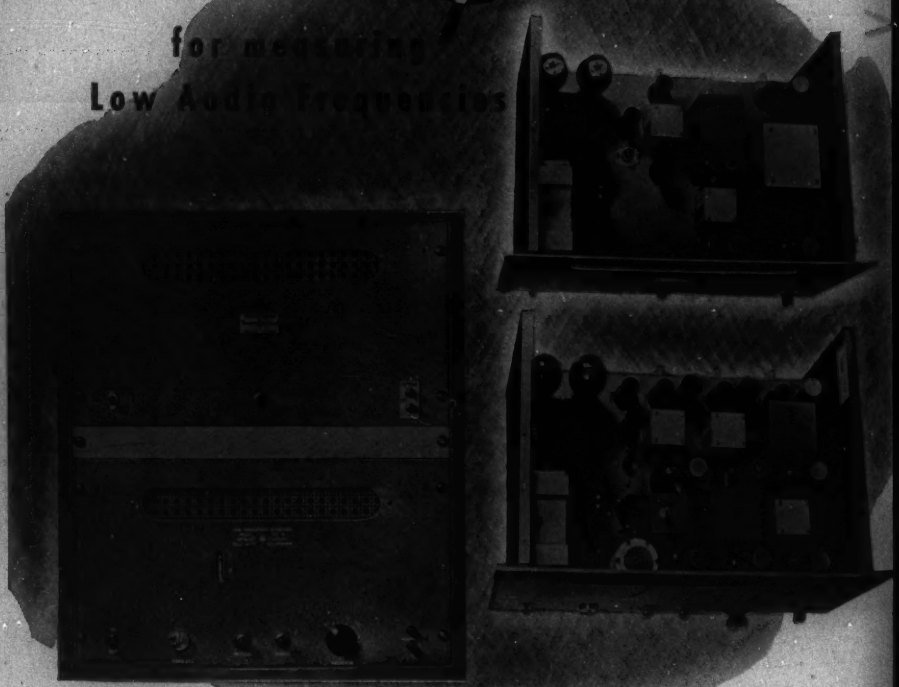

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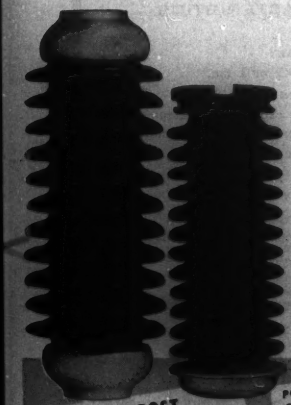

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NO PUNCTURE. *Puncture path in Lapp Post design is as great as flashover path. Insulator will flash over rather than puncture.*

NO CRACKING. *One piece post body, not subject to bursting from tension strains created by thermal changes in nested parts.*

RADIO INTERFERENCE. *By virtue of design factors alone, radio interference is permanently prevented at rated neutral voltage.*

NO CLEANING. *Fog-type design preserves uniform leakage path, prevents leakage flashover, makes the unit "self-cleaning."*

MECHANICAL RUGGEDNESS. *Stones or bullets deflect off, or rupture petticoats, leaving post body intact and insulator secure.*

Ideal Components

for V.H.F.—U.H.F. APPLICATIONS

ERIE Type 370 Silver Button Mica Condensers have proven to be ideal components for V.H.F. and U.H.F. applications where short ribbon-type leads, low series inductance, and compactness are requisite factors. Their efficiency and quality have been thoroughly established through practical service, in large quantities since 1941.

These small condensers consist essentially of a stack of silvered mica sheets encased in a silver plated housing. The housing forms one terminal, the other terminal being connected to the center of the stack, thus providing the shortest possible electrical path to and from the capacitor.

A wide selection of terminal and mounting designs is available to provide both feed-through and by-pass connections. Capacity ranges and electrical characteristics are given above.

Complete technical information will be sent to interested engineers on request.

CHARACTERISTICS

CAPACITY RANGE:
15 to 500 MMF at 1 mc.

POWER FACTORS:
.08% max. for capacity tolerance ± 5% or closer (for resonant circuit applications).
.12% max. for capacity tolerance over ± 5% (for by-pass and blocking use).

MAX. WORKING VOLTAGE:
350 Volts A.C., 500 Volts D.C.
Flash Test (2 seconds) 1,000 Volts D.C.
Leakage Resistance, Over 10,000 megohms.

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FOR HIGH ACHIEVEMENT IN WAR PRODUCTION

Electronics Division

ERIE RESISTOR CORP., ERIE, PA.

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* * * Let's All Back The Attack—Buy EXTRA War Bonds * * *

IMPROVE Wiring Harness Methods with IRVINGTON Plastic Tubing and Wire Markers

Wiring harness . . . pre-fabricated wiring sub-assemblies . . . are doing much to speed the manufacture of many war products. They do this by placing the job of wire cutting, stripping, fitting and binding, where it belongs—on a sub-assembly bench.

Conductors used in the assembly of harnesses can be effectively grouped and further insulated with sleeves of Transflex, a transparent plastic tubing which then serves as a flexible, protective conduit. Transflex reduces—often eliminates—the need for lacing; has unusual elongation and may be stretched over lugs, splices and other projections. It withstands attack by moisture, oils, solvents, acids and alkalies, and may be safely used at temperatures as low as −58° F. It does not support combustion.

Irvington Plastic Marker-Insulators are useful in harness construction because they provide both terminal insulation and positive wire identification. Made of the same resistant material as the plastic flexible conduit, they are tough and elastic . . . withstand similar service conditions . . . may be used at operating temperatures up to 170 deg. F. Where continuous higher temperatures are encountered, Varnished Wire Markers are recommended.

For detailed information on these Irvington products, send for technical data sheets describing Transflex and Wire Markers. Please write Dept. 16

Colored and marked wires are easily distinguishable through Transflex plastic tubing.

Irvington Plastic and Varnished Wire Markers are both available in a variety of sizes and colors; are marked to specifications.

WIRE AND ASSEMBLY TIME SAVED WITH LATEST WIRING HARNESS TECHNIQUES

Better, faster production possible with conductors cut to proper lengths and provided with lugs and identifying markers. Harnesses reduce copper waste; can be bench-fabricated by practically unskilled workers.

1 Fastening lug and slipping Marker-Insulator into position on wires already cut to size.

2 Enclosing wires in Transflex plastic tubing conduit eliminates need for lacing.

3 Connecting harness wires to corresponding equipment terminals.

4 Completed unit ready for testing. Markers simplify inspection, "in-production" changes, and servicing.

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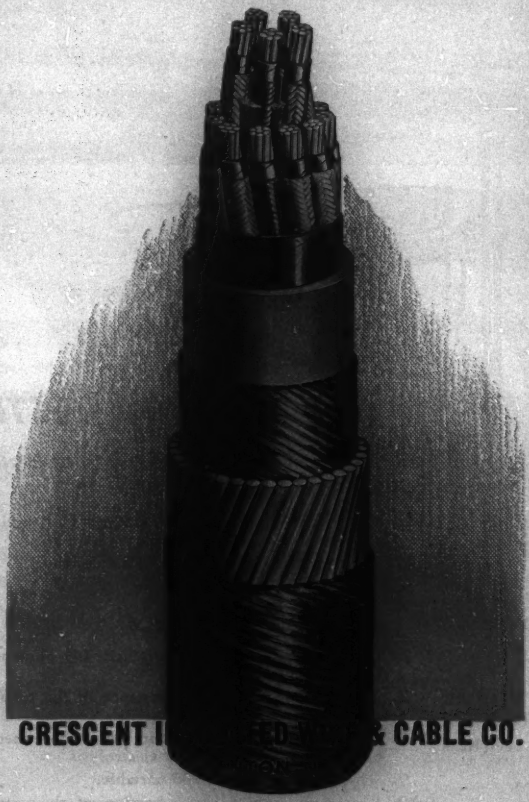

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RCA

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With this new model, many smaller communications and industrial applications can have Transtat's smooth control, high efficiency and ruggedness. An ideal component, this transformer—type a.c. voltage regulator is but one-half the size and less than one-half the weight of the smallest previous TH Transtat.

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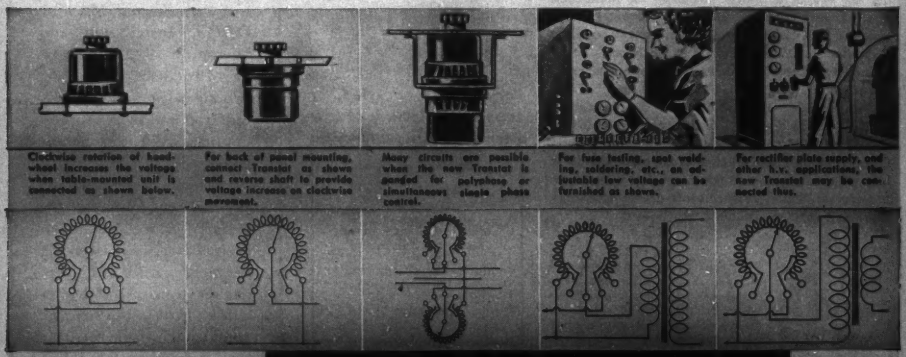
The unique brush arm shaft mechanism provides ease of change from table mounting to back of panel mounting or ganging. Die cast brush arm permits quick brush changes, improves heat dissipation and has generous brush contact area. Other features include extra wire insulation and impregnation of core and coil with special synthetic phenolic varnish. For complete details write for bulletin.

AMERICAN TRANSFORMER COMPANY, 178 Emmet St., Newark 5, N. J



Clockwise rotation of handwheel increases the voltage when table-mounted unit is connected as shown below.

For back of panel mounting, connect Transtat as shown and reverse shaft to provide voltage increase on clockwise movement.

Many circuits are possible when the new Transtat is ganged for polyphase or simultaneous single phase control.

For fuse testing, spot welding, soldering, etc., an adjustable low voltage can be furnished as shown.

For rectifier plate supply, and other h.v. applications, the new Transtat may be connected thus.

Pioneer Manufacturers of Transformers, Reactors and Rectifiers for Electronics and Power Transmission

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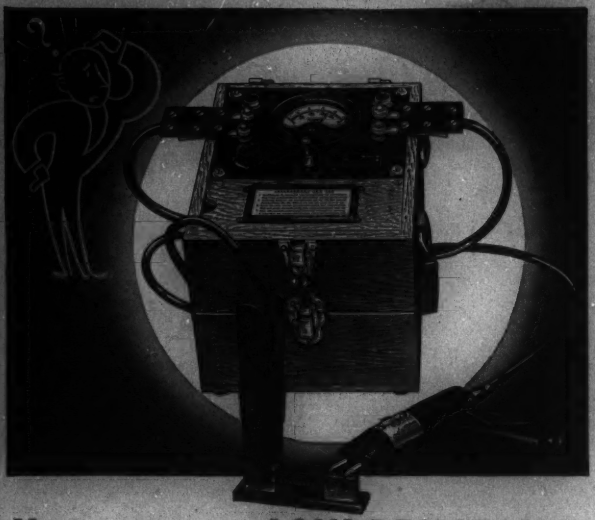

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. . . from 10 ohms to .00005 ohms

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Shallcross Low Resistance Test Sets are available in a variety of portable and semi-portable types to facilitate the making of a large number of tests without the use of a bridge. Whether for production line testing of contact resistance of electrical equipment, or field testing of railway or aircraft bonding, they offer maximum efficiency and economy.

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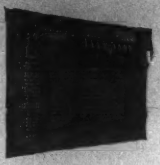

The switchboard illustrated is manufactured by Electric Service Control, Inc., Newark, N. J. It is designed to start an emergency Diesel upon failure of normal service and then transfer the load to the emergency source. Upon restoration of normal service the load is automatically restored to it.

That Electric Service relies upon ASCO Automatic Transfer Switches and Relays for this important application is evidence of their adaptability and reliability.

We also manufacture a line of Solenoid Operated Valves for Automatic and Remote Control of Liquids and Gases

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AMPERITE REGULATORS

Features:

1. Amperites cut battery voltage fluctuation from approximately 50% to 2%.
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3. Compact . . . light . . . and inexpensive.

DELAY RELAYS: *For delays from 1 to 100 seconds. Hermetically sealed. Unaffected by altitude. . . . Send for catalogue sheet.*

NEW! 8-page folder will help you solve Current and Voltage Problems—contains much valuable data in practical form—Write for your copy now.

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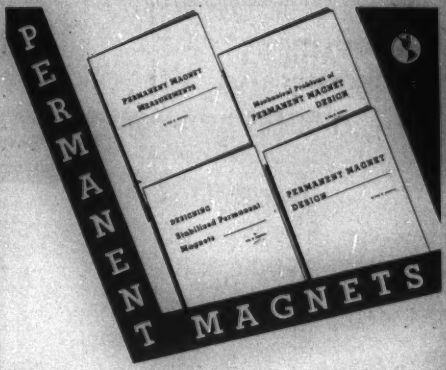

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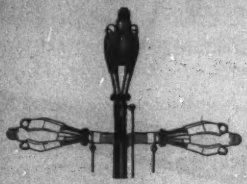
MATTHEWS HOLDFAST LAMP CHANGERS



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To remove or replace lamps from side walls or at an angle, pull cord attached to the swivelled ring. This bends the wristlike coil spring so that the Changer will work just as well at a right angle to the rotating pole as in vertical position.

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For 50-Watt Rough Service, 15 to 100 Watt Mazda and other lamps up to 3 inches in diameter.

No. 2	Less Than 6	6 to 11	12 or More
Price Each	$5.00	$4.75	$4.50

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For 60 to 500 Watt Mazda Lamps and other large and odd shapes up to 5 inches in diameter.

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Price Each	$5.50	$5.25	$5.00

All Prices F.O.B. St. Louis, Mo.

Specially treated wood handles can be furnished in 6-foot sections at $3.75 per section including couplings.

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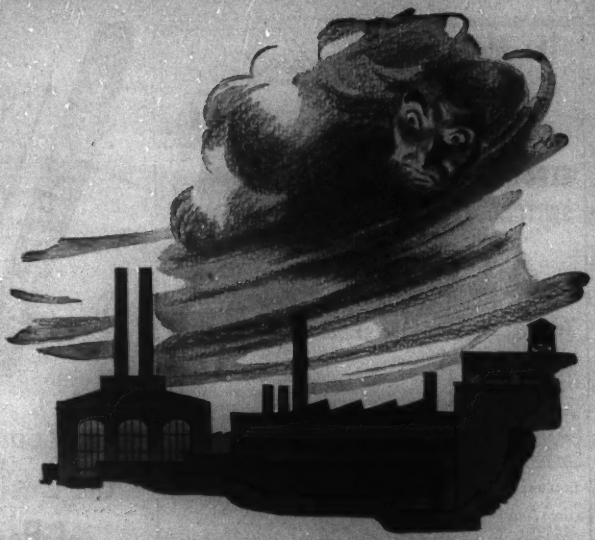

Does a Saboteur Menace Your Power Plant?

Is heat baking out the insulation on your wiring? Is moisture raising havoc with your motors? Or could it be that corrosive vapors are causing frequent power failures? The work of any one or all three of these sabotage agents will ruin ordinary power cables. Today that's serious because a break in your power circuits may mean a delay in some plants' war production.

The next time you make an inspection trip around your power plant, check the torrid zones where these saboteurs may be busy at their destructive work. Then rewire with Deltabeston Power Cable. You'll find there's no better protection for general wiring in power plants where severe operating conditions exist.

Deltabeston Power Cables Types AVA and AVL are also ideal in steel mills, boiler rooms and in other places where constant high temperatures prevail. Deltabeston is insulated with asbestos purified by an exclusive process which gives it great heat resistance. The purified asbestos is "felted" to the flexible copper by a patented method which produces an extremely tight bond. The asbestos is then impregnated with a special compound to make it highly resistant to moisture and corrosive vapors.

For additional information write to Section Y841-32, Appliance and Merchandise Dept., General Electric Company, Bridgeport, Conn. G-E Deltabeston wires are distributed nationally by Graybar Electric Co., G-E Supply Corp. and other G-E Merchandise Distributors.

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EVEN A BROADSIDE DOESN'T JAR THE PLUG OUT OF THIS RECEPTACLE

Another Engineering Accomplishment of The Hubbell Development Laboratory

ELECTRICAL connections aboard modern warships must withstand the shock of gunfire as well as the normal vibration of operation. When ordinary outlets were used for plugging in portable electrical equipment, considerable trouble was experienced with plugs working loose, or being ejected by the recoil of a broadside. This problem was solved with a product of the Hubbell Development Laboratory.

The Hubbell Twist-Tite Receptacle now used on various classes of Naval vessels firmly grips all standard parallel-blade plugs. This is an enormous advantage. It assures the Navy of vibration-proof connections without the necessity of putting special plugs on the extension cords of all the clocks, fans, vacuum cleaners, radios and similar equipment used on every ship.

The function of the Hubbell Development Laboratory is to help industry meet its ever-changing need for electrical connectors, switches, sockets and receptacles. Most such devices on the market today originated in, or have been improved by the Hubbell Laboratory. If you have a problem within the scope of the Laboratory, let us know about it. We will gladly have a local technical adviser call on you.

HOW THE HUBBELL "TWIST-TITE" WORKS

Besides the advantage of the elimination of accidental plug disconnection, TWIST-TITE always assures a continuous, uninterrupted flow of current. The Laboratory has also developed a complete line of TWIST-LOCK connectors used extensively by industry where an absolute locking device is desired.

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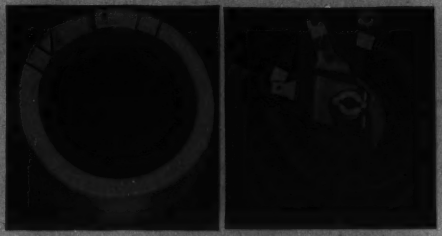
THE WIRE IS WOUND
ROUND AND ROUND



THIS UNIVERSAL PORCELAIN CORE

Ohmite Vitreous Enamel Rheostats have won an enviable reputation with engineers and in industry. And each Ohmite rheostat going into service adds proof to the evidence that Universal porcelain parts have definite advantages in electrical applications of rigid performance requirements. Universal genuine porcelain insulators have high dielectric strength; withstand thermal shock and arcing; are non-corrosive; resist acids and will not carbonize because they contain no organic binders. Send blueprints of parts and specifications for estimate. No obligation.

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Specialists for over
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ROWAN CONTROL
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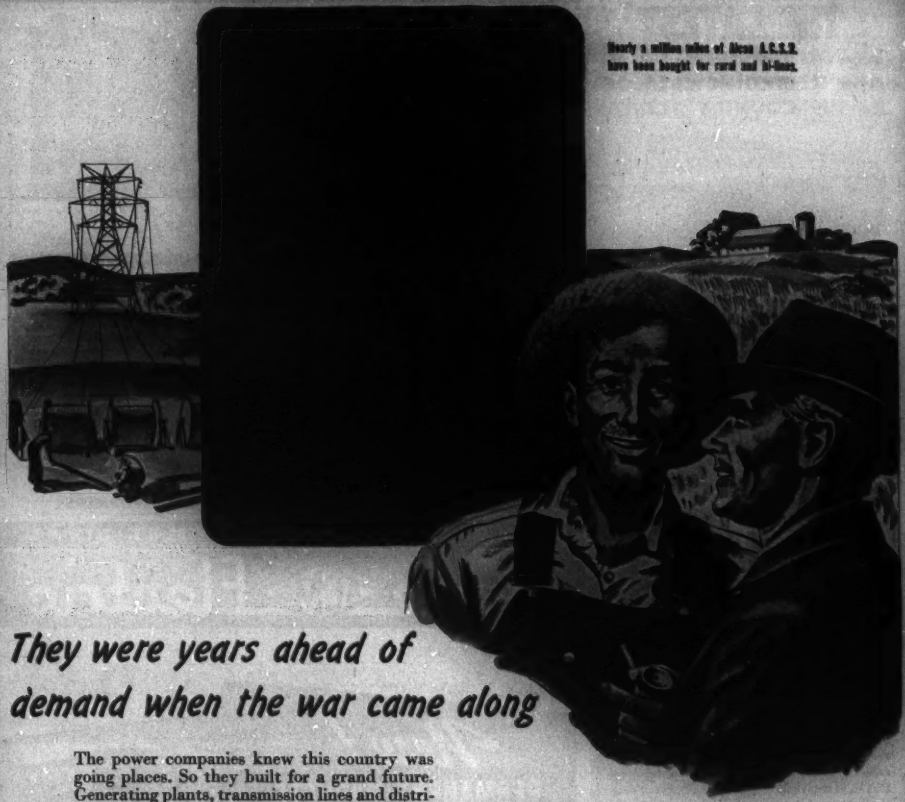

They were years ahead of demand when the war came along

The power companies knew this country was going places. So they built for a grand future. Generating plants, transmission lines and distribution facilities were designed on a scale which would place no limitations on that growth.

Then came the war. The country's demands for electricity soon gobbled up surpluses of generation and distribution. A power famine threatened.

But the utilities saved the day. Not only did they cut into service every ounce of reserve, but they uncovered an ingenuity which made heavy producers out of middleweight equipment. Generators, transformers, switching apparatus, all have been overloaded to the point of exhaustion, cancelling much from their life expectancy, but carrying the country over the hump.

Power lines and underground cables have been loaded to suit the weather, running hotter on cool days, when excess heat could be dissipated. Substitute materials and makeshift methods were employed, just as in other industries, to patch up and extend vital lines. Critical materials were saved for war.

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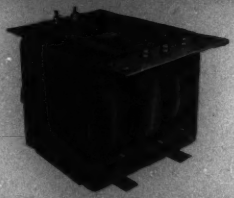

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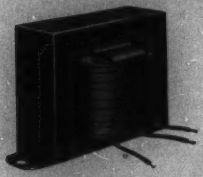

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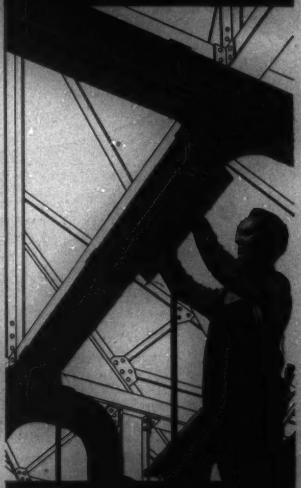

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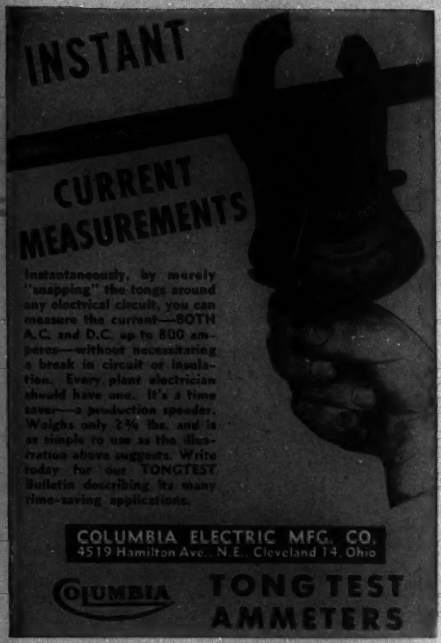
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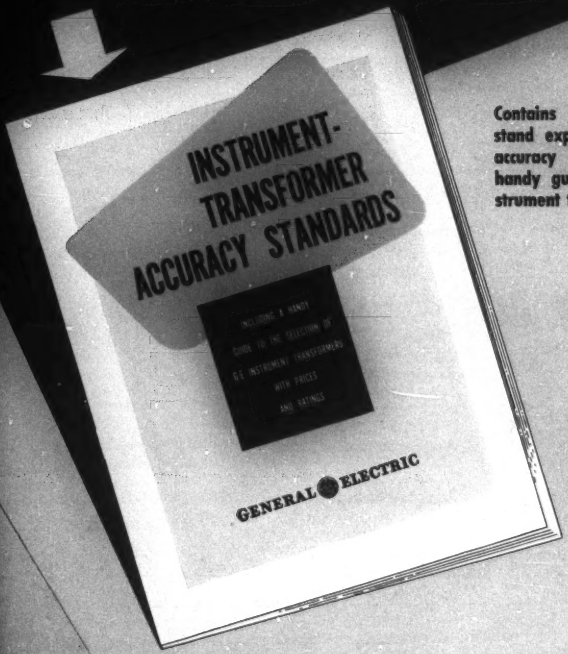

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